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New York State Museum

JOHN M. CLARKE, Director

Museum Bulletin 145

GEOLOGY OF THE THOUSAND ISLANDS REGION

ALEXANDRIA BAY, CAPE VINCENT, CLAYTON, GRINDSTONE AND THERESA QUADRANGLES

BY

H. P. CUSHING, H. L. FAIRCHILD, R. RUEDEMANN AND C. H. SMYTH JR

ALBANY

UNIVERSITY OF THE STATE OF NEW YORK

1910

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New York State Education Department
Science Division, October 4, 1909

Hon. Andrew S. Draper LL.D.
Commissioner of Education

SIR: I have the honor to communicate herewith for publication as a bulletin of the State Museum a manuscript entitled *Geology of the Thousand Islands Region*, covering the areas known as the Alexandria Bay, Cape Vincent, Clayton, Grindstone and Theresa quadrangles. This is a report upon several seasons of field work in the region referred to, by Prof. H. P. Cushing, Prof. Herman L. Fairchild, Dr Rudolf Ruedemann and Prof. C. H. Smyth jr of this staff.

Very respectfully,

JOHN M. CLARKE
Director

State of New York
Education Department
COMMISSIONER'S ROOM

Approved for publication this 5*th day of October* 1909

A. S. Draper

Commissioner of Education

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INTRODUCTION[1]

The field work on which the accompanying report is based was done during the field seasons of 1906, 1907 and 1908. The district was chosen for work chiefly on the recommendation of Professor Smyth, and work was begun by the writer with the understanding that we were to collaborate in doing it. Unfortunately this plan failed of realization, owing to Mr Smyth's inability to take the field, so that his actual participation in the work was limited to a portion of the season of 1908, during which he mapped the major portion of Wellesley island.

Dr Ruedemann assisted in the mapping of the southern part of the Theresa quadrangle during two weeks of the season of 1907 and in 1908, mapped Cape Vincent and the southern half of Clayton. The remainder of the areal mapping is the writer's contribution, comprising the Theresa, Alexandria and Grindstone sheets (with the exception of Wellesley island) and the north half of Clayton.

NOTE. The photographs credited to Ami and Ulrich are published by permission of the Directors of the Geological Surveys of Canada and of the United States.

[1] By H. P. Cushing.

Professor Fairchild spent the season of 1908 and portions of two previous seasons in the study of the Pleistocene geology of the area, and his reports will be found included in their appropriate places.

During both the seasons of 1907 and 1908 Dr E. O. Ulrich of the United States Geological Survey was in the field for a time with Dr Ruedemann and myself. In 1908 Dr H. M. Ami of the Geological Survey of Canada was also present and we spent 10 days together, chiefly in study of the Pamelia, Lowville and Black River limestones, with a short excursion to the district around Kingston, under Dr Ami's guidance. Combined work of this sort is of the utmost value, and as a result of it the indirect contribution of both these gentlemen to this report is most important and is gratefully acknowledged.

In a previous year Professor Smyth had reported upon the larger part of the district comprised in the Alexandria and Grindstone sheets, as well as their eastward extension, doing the work as accurately as the imperfect base map at his disposal warranted. It is a pleasure to testify to the importance and accuracy of this report, especially in view of the date at which, and the circumstances under which the work was done.[1] The different rock groups and their relations to one another were thoroughly worked out, and the independent mapping here reported upon has done little more than to repeat his work and emphasize its correctness. This of itself would justify his appearance as a collaborator in this report, independently of his direct contribution.

For five weeks of the season of 1908 Dr H. N. Eaton of Chapel Hill, N. C., served as voluntary assistant. This generously given help is gladly acknowledged, and the report also bears witness to the service of his camera.

LOCATION AND CHARACTER [2]

These five quadrangles constitute the extreme northwestern portion of northern New York, bordering the lower end of Lake Ontario and the St Lawrence river in the Thousand Islands region. The area mapped extends from the meridian of 75° 45′ w. longitude to Lake Ontario and from latitude 44° to the national boundary. It comprises some 560 square miles.

[1] Geology of the Crystalline Rocks near the St Lawrence River. N. Y State Geol. 19th An. Rep't 1899. p.r85–104.

[2] By H. P. Cushing.

The area is one of low altitude and comparatively little relief, forming the west end of the plain which borders the entire north front of the Adirondack highland, and merges hereabouts into the north end of the Black river lowland. To the southward the altitude considerably increases and a bit of the high Trenton escarpment which forms the west wall of the larger part of the valley of the Black river, appears in the extreme southwest corner of the Theresa sheet, reaching an altitude of over 800 feet, the highest elevation in the mapped district. Altitudes considerably in excess of this appear not far to the southward on the Watertown sheet. But with this one trifling exception the highest elevations in the mapped area but little exceed 600 feet (this in the southeast corner of the Theresa sheet) and thence drop gently to the north and west to the level of the lake and river (246 feet).

Though the district is thus moderately flat, the local relief is considerable, in minor fashion. Ridges and valleys characterize the districts underlaid by Precambric rocks. The flat-lying Paleozoic rocks form plains which are fronted by steep cliff escarpments. In both cases abrupt changes of level of from 50 to 100 feet are quite common. These features also are most pronounced in the eastern part of the area and fade out westward, so that but little relief is manifested on the Cape Vincent and the larger part of the Clayton sheet.

With the exception of the St Lawrence, the Black and Indian rivers are the only streams of respectable size within the mapped area. Most of the streams flow in narrow, steep walled valleys, and no deep, broadly opened valleys have been detected. There are many features of interest in the minor drainage to which attention will be directed later on. The group of lakes of an unusual type forms a very prominent feature. Several of these lakes may be noted near the eastern edge of the Alexandria sheet and there are a few more beyond the map limits. They are not a usual feature of this part of the State. Their presence and their very localized distribution require explanation.

Glacial deposits are in small bulk in the district and much bare rock appears, with wide areas where the soil is very thin. In the limestone districts the streams show a tendency to go underground and bared limestone surfaces show considerable amount of rock removal through solution along the joint planes.

The district is largely one of small farms. Little or no forest remains on it, though there is much waste land. The largest

single area of the sort appears in the southeast part of the Theresa sheet, on which is found the western portion of the "sand plains," the great Pleistocene delta of the Black river.

Interesting historically from having been the scene of exploitation and settlement by French immigrants of high class, during the early part of the nineteenth century, the district preserves many traces of this immigration, especially in the matter of geographic nomenclature.

SUMMARY OF GEOLOGIC HISTORY[1]

The rocks of the region are readily separable into two great groups, the one of older crystalline rocks, and the other of younger sandstones, limestones and shales which rest upon the older group. The rocks of the older group are of Precambric age, are among the most ancient rocks of which we anywhere have knowledge, and are in most respects identical with the crystalline rocks which compose the great central region of northern New York, the Adirondack region, and with those of the much more extensive area which lies to the northward in Canada. These rocks, in the district here reported upon, form a narrow connecting link, or isthmus, between the exposures of these two areas, which otherwise are completely separated from one another by a belt of country of considerable width in which the surface rocks belong to the younger group. It is only in the immediate region therefore that direct connection can be traced between the old rocks of Canada and of New York, and this fact gives added interest to the study of these rocks here.

These Precambric rocks furnish us with our most ancient direct records of the history of the earth, but like most ancient records they are fragmentary and difficult to decipher. Nevertheless they plainly indicate that Precambric time was of enormous duration, involving many millions of years.

Here, as elsewhere in northern New York, these rocks consist of but a single series of water-deposited rocks, so far as our knowledge goes. This is known as the Grenville series, and comprises rocks which, originally deposited as shales, limestones, and sandstones, are now greatly changed in character and have become white, coarsely crystalline limestones, glassy quartzites, and schists and gneisses of many varieties. Curiously we have not as yet, in

[1] By H. P. Cushing. This is a simple statement of the outlines of the history of the region as disclosed by the study of the district. The detailed evidence upon which these statements are based, will follow later.

New York, been able to discover anywhere any trace of the older rocks which formed the floor upon which these water-laid sediments were deposited, though plainly, with such an origin, they must originally have been laid down on some such floor of older rocks. It follows therefore that we do not know the base of this Grenville series. Neither do we know its summit, since that has apparently been everywhere removed by erosion. Hence we can not know its thickness, though we do know that it is a very thick rock series, several thousands of feet at least.

Since the deposition of this formation it has undergone many changes. The rocks have been greatly compressed and intricately folded and plicated. They have been invaded from beneath by huge masses of igneous rocks, which have broken up the once continuous Grenville formation into separate and disconnected belts and patches, have probably engulfed and digested large amounts of it, and are likely responsible for the utter disappearance of the old floor on which the formation originally rested. As a result of this mishandling the rocks have been profoundly changed in character. They have been entirely recrystallized, with complete destruction of the textures which, as sediments, they originally possessed, and with the production of a foliation cleavage, or schistosity, due to a banded arrangement of the minerals formed by the recrystallization. In addition a quantity of contact rocks has been produced in the vicinity of, and by the action of, the igneous rocks, which interact with the others to produce rocks quite different from either, and with opportunities for manifold variation, with variation in the character of either or both sets of the original rocks. In this manner many rock types have arisen, often of puzzling nature.

The changes which have been produced in these Grenville rocks are of such nature as to lead to the confident belief that they took place at some considerable depth below the surface, or in other words that a considerable thickness of other rocks then overlay them, a rock thickness which subsequently disappeared because of surface wear continued through long ages.

Igneous intrusions

As has been implied the Grenville sediments are the most ancient rocks of which we have definite knowledge in northern New York. Subsequent to their formation they were repeatedly invaded from beneath by igneous rocks in molten condition. In the immediate district the bulk of this igneous rock consisted of granite, and

the more basic rocks which appear in large quantity further east are but sparingly present. But granitic intrusion took place on a large scale at least twice, probably three times, and possibly several times. This it was which was so effective in breaking up, altering and destroying wholesale the Grenville sediments and their floor.

Laurentian granite gneiss. The oldest of these igneous rocks is a granite which has, since its intrusion, been sufficiently subjected to compression to have become pretty thoroughly crushed, or granulated, with the development of a rude foliated, or gneissoid, structure. It is a reddish to gray granite gneiss which contains nearly everywhere inclusions of the Grenville rocks in varying abundance, but always most abundant near the contacts with the Grenville, into which it always sends a multitude of dikes. The inclusions are usually of amphibolite and all stages of their assimilation by the granite are found, giving rise to a group of intermediate rocks which seem unquestionably to have been derived from the digestion of the one rock by the other. It is possible that some of these amphibolite inclusions may actually represent fragments of the old Grenville floor, and furnish the sole remaining traces of that floor, but as yet this is mere conjecture. This granite gneiss occurs in both large and small masses, so called bathyliths and stocks, which invaded the Grenville rocks from beneath at an exceedingly early period.[1] In addition to forming a large portion of the present surface occupied by the Precambric rocks it likely also underlies the Grenville rocks over the entire district, except where they have been cut away by succeeding igneous rocks. Since the rock solidified it has been subjected to compression, together with the Grenville rocks, giving to each a foliation parallel to that of the other, and elongating the bathyliths in a northeast-southwest direction with corresponding shortening at right angles to this, the shortening being of course in the direction of the pressure and the elongation at right angles to it.

Alexandria syenite. On the Alexandria quadrangle, some 3 miles a little west of north of Redwood, is a mass of rather coarse grained igneous rock which shows little sign of crushing and is unquestionably younger than the Laurentian granite gneiss. In association with it is a much greater amount of a coarse, but crushed, porphyritic igneous rock, now converted into an "augen" gneiss.

[1] Bathylith is a term applied to large masses of igneous rock, which masses are believed to continue to great depths with generally increasing size downward. A stock is a smaller mass of the sort.

What relation the two bear to one another could not be definitely ascertained. Either the augen gneiss is a crushed border phase of the other, that representing an uncrushed core, or else it is a separate and older rock. It is a fairly basic rock, varying much in this respect, seems at times to owe its character to partial assimilation of amphibolite, and so far as seen, its exposed contacts are all with Grenville rocks, which it cuts. If the two intrusives belong together the mass reaches considerable size and is to be classed as a small bathylith. If the augen gneiss is distinct from the other the latter is only a stock.

In case the augen gneiss is distinct the question naturally arises whether it may not be merely a porphyritic phase of the Laurentian granite gneiss. A decisive answer to this question can not be given owing to lack of contacts between the two classes of rock. But such evidence as there is seems decidedly against such a correlation. The rock is a more basic one than the general run of the granite gneiss, and is not so severely crushed, or granulated. The weight of the evidence is decidedly in favor of the view that it is a gneissoid, border phase of the syenite.

Syenite southwest of Theresa. Up the creek valley above Theresa are exposures aggregating about a square mile in extent of a gray to gray green rock which is a syenite. It may have considerably greater extent underneath the sandstone which adjoins it on each side. It is by no means so mashed as the granite gneiss and seems clearly a younger rock, but since it is not found in association with any of the other younger igneous rocks its age relations to them are not ascertainable.

There is a single outcrop of a coarse, unmashed eruptive which is to be classed as a gabbro, close to the upper bridge at Theresa on the west bank of the river. It may have considerable extent under the adjacent sandstone but with the most generous possible allowance for such extension the mass would still have to be rated as a stock of no great size.

Picton granite.[1] The most extensive and important of these younger Precambric intrusives is the coarse red granite which outcrops widely on Grindstone, Wellesley and some of the smaller

[1] The most considerable outcrops of this rock within the State are on Grindstone island, but the name of Grindstone granite would perhaps be misleading, and Grindstone Island granite is too long a name. The smaller Picton island is however the seat of the chief quarries at the present time and the name would be wholly appropriate except for the fact that the island appears on the maps as Robbins island. It is universally called Picton island by residents, many of whom have no knowledge of any such name as Robbins island.

islands, and to a small extent on the mainland, and which is named from Picton (Robbins) island, where the most extensive quarries occur. This rock shows little or no signs of the crushing which has affected the other Precambric intrusives in greater or less degree, though it becomes fine grained in certain situations, chiefly marginal, and notably so in many of the dikes which it sends out into the adjoining rocks.

The rock holds a multitude of inclusions, of Grenville quartzites and schists, of Laurentian granite gneiss, and of the augen gneiss associated with the Alexandria syenite. Over much of Wellesley island the abundant inclusions are but little disturbed. in other words their dips and strikes are concordant and in accord with those of the neighboring Grenville rocks, and with these unchanged dips and strikes the inclusions occur in linear belts, now of quartzite, now of schists and again of granite gneiss, so that the original distribution of these rocks can be mapped as confidently as though the granite invasion had never been. This indicates that here we are near the very roof of the granite bathylith, where cooling had rendered it so stiff and pasty as to be no longer able to pluck away and engulf blocks from its roof, the present inclusions being such as had been last broken away but were unable to founder and retained their original orientation.

The utter lack of signs of crushing in the rock leads to the rather confident belief that it is the youngest of all these early Precambric intrusives, though there is some question as to whether it is actually younger than the syenite and the gabbro about Theresa, and with no possibility of definitely settling the matter.

The bathylith is also of large size, extending out of New York into Canada among the islands and on the mainland. The granite which outcrops about Kingston seems surely identical, and is distant 17 miles from the nearest outcrops of the rock on the west end of Grindstone island.

The molten mass of the granite was also richly charged with mineralizing fluids and hence exhibits prominent contact effects on the adjacent rocks, much more prominent than those shown by any of the other intrusives of the immediate region.

When compared with the Precambric rocks of the general Adirondack region (the rocks hereabouts comprising the extreme western edge of the Precambric of northern New York) the most obvious difference to be noted is the comparative scarcity of igneous rocks belonging to the syenites and gabbros in this western area.

It seems also to be the case that metamorphism is not so extreme

here as farther east, in fact there seems to be a slow but progressive increase in severity of metamorphism in passing east. The differences in this respect are not so prominent in the Grenville and Laurentian rocks as in the later igneous rocks, but characterize all. Even here, however, the character of the metamorphism indicates a considerable depth for the rocks concerned during the time when it took place. But it also suggests a less depth of overlying material than is possessed by the region farther east.

This overlying material has since been removed by slow surface erosion. Greater thickness has been removed on the east than on the west apparently, the differences in metamorphism being thus most readily explained. Further, this removal by erosion took place wholly in Precambric time indicating that the region was a land area for a long period. Precambric time however was very long, the Grenville sediments were deposited early in it, the district subsequently rose above sea level and remained as land during the long ages of the middle and late Precambric. The large amount of rock thickness removed not only argues for a long erosion interval but likely indicates renewal of uplift on one or more occasions, since it is not probable that the region ever attained an altitude as great as that represented by the thickness of rock removed.

Late in Precambric time, and toward the close of this long, erosion period, came renewed igneous activity, an upward movement of heavy, black, basic lava taking place. Not improbably some of this material reached the land surface of the time and spread out as lava flows. If so subsequent wear has removed every trace of their presence, cutting away the surface sufficiently so that the only sign of this igneous activity which remains on the surface of today is the trap dikes, the lava-filled channels of ascent of the molten rock. The trap is absolutely unmetamorphosed and gives every indication of having solidified at quite shallow depth. Hence the conclusion is forced that the eruption occurred toward the close of the long Precambric erosion period previously described, and since only a comparatively slight amount of wear followed, that these dikes are of very late Precambric age; in fact it is by no means impossible that they may be as young as the early Cambric.

If we could follow these dikes down into the earth beneath the surface of today, no doubt we should find that they lead upward from underground masses of trap of considerable size, quite analogous to the bathyliths of the earlier granites.

Close of the long period of erosion

Eventually this long period of surface wear on a land area drew to a close, and for a time the history of the region became of very different nature, in other words instead of loss of surface material it began to gain it in the shape of deposits on the old, worn land surface. These deposits blanketed and preserved the old erosion surface, and since the wear of today has come down to that precise horizon over parts of the district, and the overlying deposits are being peeled away from it, it is returning to daylight with precisely the characters it possessed when it was buried and preserved ages ago. Seldom does a district reveal so abundant and clear evidence of the nature of an old fossil land surface. It is clear from its study that long wear had reduced it to a surface of comparatively slight relief, showing that no considerable elevation of the region occurred during the latter portion of the long erosion interval. Nevertheless it is very far from being a plane surface, but is of considerable minor relief, of low ridges and shallow valleys, or of low knobs and basins, the depressions eaten out on the weaker rocks, chiefly the Grenville limestones and some of the schists, while the more elevated ridges and knobs are due to the resisting qualities of the Grenville quartzites and of many of the igneous rocks. The knob structure is practically confined to the igneous rock areas, chiefly in the Laurentian gneiss.

While the region therefore is quite rugged in a mild fashion, the extreme differences in altitude are but slight. One hundred feet is about the measure of difference. Seldom does the difference in level between valley bottom and ridge crest reach that figure, and rarely does it exceed it. This is a small difference, considering the wide variation in resisting power to wear which the various rocks present and is indicative of a long period of wear under comparatively stable conditions of level.

Paleozoic sediments

Potsdam sandstone. A change in conditions followed and deposition of sand commenced upon this old land surface. It naturally began on the valley bottoms and encroached on the ridges only as the valleys filled. The old limestone surfaces were pitted by small depressions, and were somewhat intersected with widened joint cracks also, and in these the first materials collected, sometimes full of coarse fragments of resistant thin quartzite bands or

granite dikes such as are found nearly everywhere in the Grenville limestones, sometimes containing only sand. There is comparatively little basal conglomerate in the district back from the river, but there, both on the mainland of the Alexandria quadrangle and on Wellesley and Grindstone islands is an exceedingly coarse conglomerate, from 10 to 20 feet thick, full of coarse cobbles derived from the ponderous and resistant Grenville quartzite of the vicinity.

Except for these conglomerates the formation is everywhere a sandstone and mostly pretty thoroughly cemented, the cement being chiefly of silica. Its colors are red, brown, yellow, white, and rarely black. Its thickness over the immediate district will scarcely exceed 100 feet, and it thins out toward the west and south. The deposits of sand began forming first in the Champlain region and gradually worked their way westward, being deposited in a shallow trough or basin whose axis roughly coincided with the modern St Lawrence axis, so that hereabouts we find simply the thinned western edge of the formation. As its thickness here is substantially equal to the difference in altitude between the ridge crests and valley bottoms of the old erosion surface upon which it was deposited, it follows that it varies rapidly in thickness from place to place and was but scantily deposited upon the elevations, some of which it utterly failed to overtop.

It is not known whether or not the formation in its entirety is a marine formation. The sparse fossils indicate such origin for the upper beds with comparative certainty, but many things about the remainder of the formation suggest a land surface and an arid climate as the conditions under which the accumulation took place.

Theresa dolomite. A change in conditions ensued and deposit of dolomite began. Some sand was still supplied from the neighboring land however, as the dolomite is everywhere sandy, and at first the supply was from time to time in excess, so that layers of coarse weak sandstone alternate with those of dolomite. Hence there is a gradation from one rock to the other instead of a sharp boundary between the two. The greatest thickness of the formation within the area mapped does not exceed 35 feet, though its original thickness may have been somewhat greater. The thickness increases eastward and diminishes to the west and south as was the case with the underlying sandstone. The waters were more fitted for the existence of life and the fossils are more abundant than in the sandstone, but unfortunately conditions for their preservation have not been favorable.

The Theresa formation followed close after the Potsdam and they were laid down in a trough or bay along the present St Lawrence line which was landlocked on the north, south and west. The depression of this trough originated to the eastward, where the deposits are thickest, and deposits did not commence in the immediate region until late in Potsdam time. The extreme western extremity of the bay can not have lain many miles west of the immediate region at the time of its greatest expansion. Then it commenced to contract and slowly work back eastward.[1]

Uplift following the Theresa. This tendency to contraction of the trough, caused by slow uplift of the land, seems to have continued until the bottoms of both the St Lawrence and the Champlain troughs had been raised above sea level, so that all the northern portion of the State was above that level. After a time renewed depression followed, apparently commencing simultaneously on the west, south and east sides of the Adirondacks, and the Tribes Hill phase of the Beekmantown formation was laid down. This was followed by uplift which began at the west and worked eastward, bringing the west and south sides of the district above sea level, while subsidence still continued in the Champlain valley, in which a large thickness of later Beekmantown rocks was deposited. This Tribes Hill subsidence came in on our district here from the south and its deposits constitute the upper portion of what is mapped as the Theresa formation. Until the Beekmantown formation along the St Lawrence valley has received further study we can not say whether the Tribes Hill limestone extends east of the Frontenac axis or not. Our present view is that it did not, and that the Beekmantown of the St Lawrence valley represents the higher portion of the formation, deposited in a trough which extended westward up the valley from the Champlain basin. This depression did not carry the immediate region below sea level. The district tilted to the southwest and received a thin edge of Tribes Hill deposition, then rose and was tilted back to the eastward, though not sufficiently to allow the later Beekmantown sea of the district to the east to quite reach it.

[1] Since the field work was completed and this report written, work elsewhere in New York has shown that probably the Theresa formation, as here mapped and described, is in reality composed of two probably unconformable formations, of quite different ages, and that the name should be restricted to the lowermost of these, the upper being of lower Beekmantown age, and equivalent to what we are calling the Tribes Hill formation in the Mohawk valley. The matter is discussed in more detail on a later page.

In the Champlain valley the Beekmantown rocks are overlaid by the Chazy limestones. There is evidence there of a break between the two formations and the Chazy has a basal sandstone. The Champlain Chazy trough also had a westerly bay but it never extended as far west as the district under discussion. During the long time interval therefore during which Beekmantown and early Chazy sedimentation was transpiring in the subsiding Champlain trough, the district here was above sea level and experiencing wear rather than receiving deposit. Considering the length of the interval the amount of erosion which it suffered was but slight, arguing for low altitude and gentle slopes for the land. Broad, shallow valleys were cut in the surface of the Theresa limestone but the depth of cutting seems never to reach the base of the formation.

Pamelia (Stones River) limestone. The Chazy basin of the Champlain, St Lawrence and Ottawa valleys was landlocked to the south and west during lower and middle Chazy time. During this time interval, however, other and larger basins of subsidence and deposit existed to the south and west but completely separated from the Chazy basin. Both the rocks and the contained fossils therefore differ from the Chazy and the formation is known as the Stones River. Notwithstanding difference of name the two formations represent substantially the same time interval.

As Chazy time passed on, the large Stones river basin to the southward encroached northwardly and toward the latter part of the interval had become sufficiently extended to submerge the immediate district. The slow warping of the land which brought about this subsidence gave the district a wholly different direction of slope. In Potsdam and Theresa times it had sloped to the northeast and formed part of the extreme westerly end of the subsiding trough. It now came to slope to the southwest, was invaded by the sea from that direction, and to the northeast lay a land area which separated it from the Chazy basin beyond. Though the district was covered by the waters of both marine invasions it was near the shore line in each case and received only comparatively thin, marginal deposits, representing only a small fraction of the entire thickness of the formations concerned. Hence in a broad way it is true that what had been the western shore of the earlier sea became now the eastern shore of this later western sea, or that the general district formed an axis or pivot from which the land tipped now in one direction

and now in the other, remaining throughout an area of small subsidence.

The deposits laid down in this depression are of upper Stones River age and the name of Pamelia limestone is proposed for this New York phase of the formation. Locally it is known as the " blue limestone " though the local name commonly includes the overlying Lowville limestone as well. A thin, basal sandstone appears, after which follow alternating black, blue and gray limestone beds, then the black limestone disappears and white, earthy limestone alternates with the others. During the deposit of this upper portion the waters seem to have become shut off from the open sea, by the development of some shoal or reef as a barrier, and in the lagoon thus formed water lime was deposited, the waters often evaporating sufficiently to expose wide mud flats which dried and cracked under the sun's influence. The marine fauna found these conditions uncongenial and disappeared, though returning from time to time for a brief space with fresh influx of water from the sea outside. Deposition became intermittent and eventually ceased and some slight wear occurred locally.

Lowville, Watertown and Trenton limestones. Subsidence then recommenced, and upon this slightly worn Pamelia surface the dove-colored limestones of the Lowville formation were laid down. The Lowville submergence was somewhat more extensive than the Pamelia, since the former appears in the Mohawk valley while the latter does not. And though both formations occur along the Black river valley it seems probable that the Lowville sea encroached more widely upon the borders of the land which lay to the eastward.

The Lowville is a quite pure limestone for the most part, and carries a much more abundant and varied marine fauna than do any of the older rocks. Above it lies a more massive, cherty limestone, separated from the main mass of the Lowville by an unconformity, which we are calling the Leray limestone, and classing as an upper member of the Lowville. Above this, also with an unconformity between, comes a similar massive limestone, without chert, which we are proposing to call the Watertown limestone. The Watertown and Leray limestones taken together are known in the region as the Black River limestone, the Leray being locally more like the Watertown than like the Lowville in character. Because of this, and because of their small thickness (about 10 feet each), we have felt constrained to map them together. They carry

an abundant marine fauna, the large cephalopods being especially conspicuous.

The Watertown limestone is unconformably overlain by the thin bedded limestones of the Trenton. The time interval between the Lowville and the Trenton was a considerable one, but the surface exposures of these rocks in New York are so near the old shore lines of the time, that the deposits exposed represent the interval very imperfectly. The shore line was one of many and frequent local oscillations, and the rocks which have, of late years, been classified as Black River limestone, represent very different parts of this general interval.

The Trenton limestone is abundantly fossiliferous and has a thickness of 400 feet or more in the immediate region, exceeding the combined thickness of the Potsdam, Theresa, Pamelia, Lowville and Black River together. Found on all sides of the Adirondacks, and with large thickness everywhere, the Mohawk valley excepted, large subsidence is shown, with probable great encroachment of the waters upon the Adirondack island, much diminishing its size.

As Trenton time drew to a close fine muds commenced to appear in the waters, brought in by currents from the northeast, and in slowly increasing amount. Hence the limestones become impure and grade upward into black shales, at first strongly calcareous, later on lacking lime. This change came on the region from the eastward, hence shales were forming there while limestone was still being deposited on the west. But the change to mud deposit spread slowly over the whole region and the Trenton is found everywhere to be overlaid by the black Utica shales. This Utica submergence seems to have been the most extensive in the State's geologic past, and it is quite possible that the entire Adirondack island was submerged. If so it seems to have been the last time that such was the case, as it was the first.

Above the Utica lie the lighter colored shales and shaly sandstones of the Lorraine formation, the combined thickness of the two shale series being several hundred feet. While neither formation is found within the limits of the area mapped, in which the lower Trenton is the youngest rock found, yet they outcrop in great thickness on the Watertown quadrangle and reach to within 6 miles of the south margin of the Theresa sheet, and it seems quite certain that they were originally deposited over part, and likely all, of the district mapped, and are now absent from it because of subsequent erosion. It is even probable that the Oswego and Medina sandstones, thick sand formations which overlie the Lorraine shales,

and whose present northern margin of outcrop is distant but 15 miles from the map limits, may also have been somewhat deposited within it. Certainly the sandstone extended orginally farther north than now, but just how far no one can say.

The deposit of these sands indicates a shallowing of the waters over the region, following which it was uplifted above sea level. Thenceforth in the main, throughout the millions of years which have since elapsed, the district has remained a land area. It is quite possible that the succeeding Siluric and Devonic seas, whose waters covered central and western New York, may have washed over this district, and laid down thin deposits. But if so, every trace of such deposits hereabouts has disappeared through erosion, so that no certainty can be arrived at in the matter.

As a result of the various oscillations of level which the region has undergone the rocks described have been changed from their original nearly horizontal position, into a series of low folds. This folding seems to have commenced early and to have been continued on various occasions, since there is some evidence that the Potsdam and Theresa formations were somewhat folded before Pamelia deposition began. Subsequently more folding took place, involving the entire series, and though the folding is gentle its topographic expression is plain.

The principal folds have axes which trend northeast-southwest, but there is also present another set with northwest-southwest trend, or at right angles to the first set, whose arches and troughs are thus folded up and down, producing gently elevated domes and depressed basins, the former where the arches of the two sets cross, and the latter at trough intersections. Many of the outliers shown on the accompanying geologic maps owe their existence and preservation to this folding.

Subsequent history of the region

But little that is definite can be said of the history of the district during its long existence as a land area following the deposition of the rocks previously described. It seems quite certain that the amount of rock worn away from the surface during this time is slight, considering the length of the time interval, and that therefore the land has seldom had any considerable altitude. Where the entire thickness of overlying rocks has been worn away and the Precambric exposed at the surface, as is the case on parts of the Theresa and Alexandria sheets, it seems quite certain that not

over 3000 feet of rock thickness has been removed, and likely considerably less. Since the overlying rock has been worn away down to the Precambric over only a small portion of the whole district, it follows that in the remainder the erosion has been less than the above amount by the remaining thickness of such overlying rock. The character of the district to the south of the map limits however indicates an uplift of the land of *comparative* recency to the amount of several hundreds of feet, and the present-day stream valleys of the region have been worn down below this old level in this comparatively recent period. This relatively considerable recent elevation and erosion makes still more emphatic the necessity for assuming slight elevation of the region during the much longer interval which preceded it. As compared with much of the district surrounding it this area has been one of but slight changes of level during its past history. While in their early history these surrounding districts were submerged and subsiding, allowing thick accumulations of deposits, this area subsided less and received but scanty deposit. Only during middle and late Lower Siluric time, during Lowville, Trenton, Utica and Lorraine deposition, was it a district of considerable subsidence and deposit. In its subsequent history as a land area it seems to have been one of but small uplift as compared with much of the adjacent region.

As has been stated, in the comparatively recent past the district experienced uplift to the amount of several hundred feet. Prior to this it had been worn down to a surface of comparatively slight relief. The uplift gave the streams power to deepen their valleys by an equivalent amount, and the processes of wear which have given the present relief to the region were set in motion. Then, as now, the Black river was the chief stream of the neighborhood, and perhaps turned west into the Ontario lowland as it now does; but the lake was not in existence then, nor was the drainage of the lowland to the eastward, but the Black river flowed through it in a westerly direction, receiving many tributaries from the north and the south. There were also easterly flowing waters in the district, however, the beginnings of streams which drained down the St Lawrence valley. But the St Lawrence of the time had its sources in the immediate region, and contained no waters coming from farther west, the divide between the easterly and westerly flowing waters being here, crossing the present St Lawrence in the Thousand Island region on the hard rock barrier which the Precambric rocks furnish. On the New York side the divide can be traced across the Clayton, Alexandria and Theresa quadrangles in a south-

easterly direction, with sharply cut ravines heading against it on both sides, marking the extreme heads of the small streams which flowed on the one hand northeast to the St Lawrence, and on the other hand southwest to the Ontario drainage. On the Clayton quadrangle the French creek valley belongs to the former, and the Chaumont river valley to the latter category; on the Alexandria most of the country was on the St Lawrence side of the divide, the valleys of Crooked creek, Cranberry creek, Butterfield lake-Black creek, and the valleys now occupied by the other lakes belonging there, while Mullet creek valley drained the other way; on the Theresa the valley into which the Indian river breaks at Theresa village seems to belong to the easterly drainage, while the remainder of the valleys on the quadrangle carried water to the westward drainage.

The valleys excepted, the prominent topographic feature of the region is the rock cliffs, usually low, which mark the edges of outcrop of the various formations, and which owe most of their present relief to the wear which followed the considerable uplift. In general, each rock formation of the region is somewhat less resistant to wear than the formation beneath and somewhat more so than the formation above. Hence the overlying formation tends to be slowly stripped away from that beneath, which yields more slowly and, because of the nearly horizontal attitude of the rocks, remains as a comparatively flat terrace, above whose level stands the receding front of the overlying formation, while in the opposite direction the lower formation has its terrace terminated by a similar front which drops down to the level of the formation next underlying. Each formation then shows a receding front of the sort, the Theresa above the Potsdam, the Pamelia above the Theresa and so on. Because of the greater thickness of the formations the Trenton and Pamelia fronts are the highest and the most conspicuous as topographic features. The Trenton front only gets within the map limits in the extreme southeast corner of the Theresa sheet, but the Pamelia front can be followed as a cliff of more or less prominence across the Theresa and Clayton quadrangles, until the formation is lost beneath the river. This is the kind of topography invariably produced when a district of nearly horizontal rock formations of varying resistance is being worn down, but the general type is magnificently illustrated in the region here.

The Pleistocene[1]

During the geologic periods of the Devonic, Carbonic and Permic, and the Mesozoic and Cenozoic eras, each millions of years in length, our area was doubtless always above the sea and subjected to the wasting processes of atmospheric erosion.

Closing the immensely long time of erosion and bringing the history down to the present time, three geologic episodes are conspicuously recorded in the existing surface features. The first of these episodes was the burial of the entire area for some scores of thousands of years under the Labradorian ice sheet with its grinding flow. The second was the burial for further thousands of years under glacial and marine waters that immediately succeeded the latest of the ice bodies. The third episode is the present time, a restoration of the subatmospheric conditions of erosion, which has endured, probably, some 10,000 or 20,000 years.

It is now comparatively certain that during the long geologic history great changes of climate have occurred. The idea, once prevalent, that there had been during all geologic time a steady lowering of temperature and refrigeration of climate from a primitive condition of excessive heat and moisture is wholly an error. The oldest rocks of sedimentary origin contain records of glaciation. In the Permic, ice work was great and wide-spread, and glaciation was probably frequent during past time in elevated regions now eroded. The warm climate of the middle Tertiary was followed by glacial cold in northern lands, and all of New England, New York State and the basin of the Great Lakes was deeply buried under successive sheets of ice which had their origin or centers of accumulation in Canada and Labrador. The peculiar effects of the glacial invasions will be described in a later chapter.

Following at least the latest of the ice sheets the entire area under description was buried for some thousands of years beneath waters held up to high levels by the glacier acting as a barrier across the St Lawrence valley. The shore features and deposits characteristic of lake action are found over the region.

During the time of the ice retreat this portion of the continent was lower, or nearer ocean level, than at present, and when the ice barrier melted away in the St Lawrence valley, the glacial waters (Lake Iroquois) were drained down to sea level, and the north and west sections of our area were long swept by oceanic waters, a branch of the Champlain (Hochelagan) sea called

[1] By H. L. Fairchild.

Gilbert gulf.[1] The shores of the glacial and sea level waters are conspicuously preserved in many places, and specially in Jefferson county immediately south of the area; while their sediments occupy the valleys [*see* pl. 29].

The slow tilting uplift of this part of the continent finally raised the Thousand Islands district above the ocean level and then Lake Ontario was initiated. The uplifting has continued until the outlet and lake are now 246 feet above tide.

As the lake and marine waters were slowly drained away from the gently sloping surface of the area the storms and streams resumed their briefly interrupted work, and for a few thousand years they have again been gnawing at the rocks and land surface with important effects.

THE ROCKS[2]

Precambric rocks

The Precambric rocks of northern New York, as at present known, may be most conveniently classed in four groups, (*a*) a series of old sediments or rocks laid down under water, the Grenville series; (*b*) a series of granitic gneisses of igneous origin, which cut the Grenville sediments intrusively and hold abundant inclusions of them and which, in so far at least as the immediate region is concerned, are correlated quite confidently with the Laurentian granite-gneisses of Canada; (*c*) a series of somewhat younger igneous rocks which cut and hold inclusions of both the preceding groups, which have a great development in the eastern Adirondacks but occur in less force in the immediate region, and which consist of anorthosites, syenites, granites and gabbros, the last three of which occur here in masses of usually small size; and (*d*) of much younger igneous rocks, of late instead of early Precambric age, which appear as dikes of diabase or trap, and which have some development in the region, though less abundant than in the eastern Adirondacks.

The Grenville sediments are the oldest known rocks of the region, and the fact that they are water-deposited rocks necessitates belief in the existence of a floor of older rocks on which they were laid down. No certain trace of this old floor has ever been discovered in New York, and though it is possible that fragments of it may be contained as inclusions in the granite gneiss, we are as yet unable to distinguish such, if present, from

[1] Gilbert Gulf (Marine waters in Ontario basin). Geol. Soc. Am. Bul. 17:712–18.

[2] By H. P. Cushing.

the similarly situated inclusions of the Grenville rocks themselves. The same conditions prevail in general over the much more extensive Precambric areas of eastern Canada. Recently, however, Miller and Knight have announced the discovery, in central Ontario, of a basement to the Grenville formation, Grenville limestone being found resting on an ancient lava flow, whose surface is thought to show signs of slight previous wear.[1] Miller and Knight correlate this old lava, or greenstone, with the oldest known formation of the upper lake region, the Keewatin, which consists mainly of greenstones, old lava flows and beds of fragmental volcanic materials. There are present, however, some associated sediments, and Miller and Knight regard the Grenville as of Keewatin age. These are most important results and if future work fully establishes these correlations, it will follow that the Keewatin has steadily increasing sedimentary content and less and less volcanic material as it is followed eastward. By the time New York is reached the greenstones have entirely disappeared, so far as is known. At least no rocks similar to them have ever been discovered in the New York Precambric. It should also be stated that Adams is not disposed to accept the reference of the Grenville to the Keewatin on the basis of the evidence yet in hand, believing a reference to the next overlying group, the Huronian, to be more probable.[2]

However this may be, the difficulty of accounting for the disappearance of the old floor of deposit is not helped, but merely pushed a stage further back. Miller and Knight speak of only slight erosion of the old lava flow prior to the deposit of the Grenville limestone upon it. It is of course possible that this may be merely an interbedded flow of Grenville age and itself rest upon other Grenville sediments. But in any case these Keewatin lava flows and fragmental deposits are surface deposits and require the presence of a floor on which they were laid down just as much as do the Grenville sediments; but no such floor to the Keewatin is known. It is always found resting on Laurentian granite gneisses of igneous origin, or upon yet younger igneous rocks which invaded it from beneath in molten condition, cut it to pieces, and apparently engulfed and assimilated its basal portion along with the floor upon which it rested. Precisely these same conditions prevail in general in respect to the Grenville and its former floor.

[1] Bureau of Mines, Ontario. 16th An. Rep't, pt 1, p. 22–23.
[2] Adams, F. D. Jour. Geol. 16:634–35.

In New York then the Keewatin volcanics are wholly absent, except for the possibility that some of the amphibolite inclusions of the granite gneiss may be greenstone fragments considerably metamorphosed. Otherwise the Grenville sediments are the oldest recognized rocks, and they occur in patches or in belts of varying size and extent, resting on, surrounded by, and all cut to pieces by the granite gneiss and the yet later intrusions.

Grenville rocks. These rocks as originally deposited consisted of limestones, shales and sandstones, both pure and in their various transitional phases. In all probability too there was some intermingled volcanic material, though the presence of such material has never been definitely proved for the New York Grenville. The rocks have been profoundly changed in character since their formation, in part owing to great compressive stresses which operated throughout the district, and in part owing to the heat and pressure furnished by the great igneous intrusions, and also to the mineralizing agents to which these gave rise. These changes moreover were brought about early in Precambric time and under deep-seated conditions. As found today the rocks are wholly crystalline, having completely recrystallized under the severe conditions to which they were subjected, with loss of all traces of their original clastic textures. In their stead there has been developed a cleavage, or foliation, due to parallel arrangement of the mineral particles on recrystallization. The old bedding planes of the rocks can still be made out, however, in places where the composition of the original rocks changed, as where limestone was succeeded by shale or by sandstone, and from these old bedding planes it can be seen that the development of the foliation is parallel in direction to them. The original limestones have become coarse, white crystalline limestone or marble, the sandstones are now hard, glassy quartzites, while the shales and impure limestones and sandstones have become schists and gneisses of many types, while yet other varieties are contact rocks whose nature is due to action of the intrusives upon adjacent sediments. The variety of rocks is so great that it would be a hopeless task to attempt to map them all upon any such scale as that of the maps which accompany this report. One or more beds of very thick limestone occur, such as that along the Indian river northward from Theresa, or that along Butterfield lake; thick quartzites also occur, especially on Grindstone and Wellesley islands; a large thickness of green schists of a peculiar type is found to the south

Grenville green schists near the St Lawrence at Forsters landing. Alexandria Bay quadrangle, 2½ miles south of Chippewa Bay. Strike of schists n. 25° e. and dip 55° e. View looks north. H. P. Cushing, photo, 1908

and southwest of Alexandria Bay. But the bulk of the Grenville of the district occurs as a great schist series, with rather rapid alterations of varying types in bands of no great thickness, and interbanded with these are thin limestones and quartzites. After trial of various methods it was found that, on a map of this scale, and with rocks of this rapidly varying character, no further subdivision of the Grenville was possible than a separate mapping of the thicker limestone and quartzite beds, the entire remainder being mapped singly as a schist formation. It is feared that even this amount of subdivision has resulted in a map too complicated for easy use.

It was hoped that the careful, detailed mapping attempted might solve the problem of the order of superposition of the rocks and give some definite idea of the thickness of the whole. The outcome was disappointing and neither hope distinctly fulfilled, though some results were obtained. The mapping therefore is purely lithological and not on a structural basis, as it was endeavored to make it.[1]

The average trend, or strike, of the Grenville rocks is to the northeast. The direction to be sure varies considerably, swinging around to the north on the one hand, and to the east or even somewhat to the south of east on the other, yet these variations are not sufficiently frequent to offset the general statement. The dips are usually high, seldom less than 45° and frequently very steep or even vertical [pl. 1, 2]. Over the greater part of the area north dips prevail, but are replaced by south dips throughout a belt of country from 2 to 3 miles broad across the Alexandria quadrangle. This is certainly indicative of folding of large magnitude, and is corroborated by the fact that in many localities minor folds are clearly to be made out, and intricate minor puckering and corrugation. Of the two broad limestone belts within the map limits, the one along the Indian river north of Theresa, and the one about Butterfield lake, the former has a north, and the latter a south dip, and in each case the breadth of outcrop across the strike is about a mile. With the steep dips a thickness of about 4000 feet is indicated for this limestone in each case, and it is therefore conjectured to be the same thick stratum, with the structure synclinal. If this be the true interpretation then the complex of quartzite and

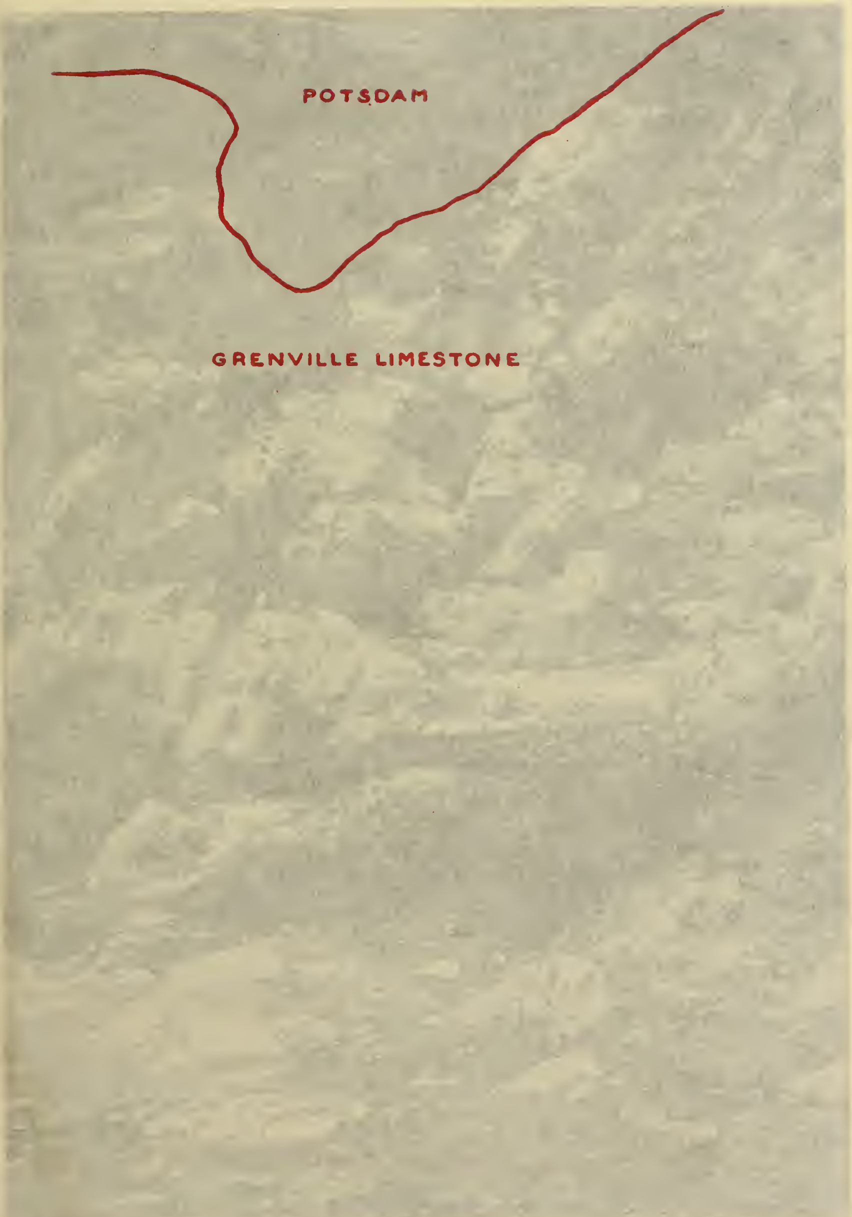
[1] Though the work was of vastly more detailed character than the earlier work of Smyth on the same rocks, it will be seen by any one who will take the trouble to compare the two maps that the basis for the subdivision of the Grenville is substantially the same in each case. No more convincing testimony could be given as to the high class character of Smyth's work.

schist, which lies between the two in the southeast corner of the Alexandria sheet, and which consists of alternating bands of quartzite and various schists of no enormous individual thickness, but which, taken together, must have a thickness of several thousand feet, rests upon the thick limestone and is the youngest portion of the Grenville exposed within the map limits. To the north, and beneath the limestone would come the great complex of green schists and impure greenish limestones which there occurs, which have steep dips and must have large thickness, at least as great as the two previous groups, and likely greater. Doubt is thrown, however, upon this interpretation by the fact that the rocks which follow the thick limestone to the south, on the Theresa sheet, differ considerably from the green schist series which follows it to the north on the Alexandria sheet, and yet according to this interpretation the two should be identical, representing the series directly beneath the thick limestone. Each does consist of schist, calcareous schist, and thin limestone bands, with an occasional thin quartzite, but the Theresa rocks are not of this distinct green schist type. A possible answer to this objection may be found in the fact that, notwithstanding a rather intimate acquaintance with the Grenville series all over northern New York and in parts of Canada, the writer has nowhere else seen the counterpart of this green schist series. It is in rather close association with the Picton granite, which was richly supplied with mineralizing agents, and is everywhere cut with numerous dikes from this granite, so that its peculiar characters are thought to be largely, or wholly attributable to this contact action, and thus explained as due to these local conditions. If this be not the explanation there seems no alternative but to regard the two thick limestones as separate beds, thus largely increasing the thickness of the section, already great. If the structure is thus correctly interpreted, a thickness of at least 20,000 feet is indicated for the Grenville of the district, and this is a conservative estimate. If the structure is not synclinal this thickness must be nearly doubled.

This matter will be discussed somewhat more in detail on a later page. The purpose here is simply to give an outline of the supposed Grenville succession and some idea of the great thickness of the series.

Limestones. The general Grenville limestone of the district is a coarsely crystalline and quite pure white marble, only sparingly charged with other minerals. The great bulk of the rock of the thick belt, or belts, just referred to, consists of 95% or upward of

Plate 2



[illegible] quarry in Grenville limestone at Theresa near the falls. The limestone bed is a thin one in the general schist series and the quarry [illegible] to show the dip here 75°. At the upper part of the cliff is Potsdam sandstone with irregular contact with the limestone and showing one of the depressed pockets characteristic of these contacts, filled with [illegible] calcareous sandstone. H. P. Cushing, photo, [illegible]

schist, which lies between the two in the southeast corner of the Alexandria sheet and which consists of alternating bands of quartzite and various schists of no enormous individual thickness, but which, taken together, must have a thickness of several thousand feet, rests upon the thick limestone and is the youngest portion of the Grenville exposed within the map limits. To the north and beneath the limestone would come the great complex of green schists and impure greenish limestones which there occurs, which have steep dips and must have large thickness, at least as great as the two foregoing groups, and likely greater. Doubt is thrown, however, upon this interpretation by the fact that the rocks which follow the thick limestone to the south on the Theresa sheet, differ considerably from the green schist series which follows it to the north on the Alexandria sheet and yet according to this interpretation the two should be identical, representing the series directly beneath the thick limestone. Both sets consist of schists, calcareous schist and thin limestone bands, with an occasional thin quartzite, but the Theresa rocks are not of this distinct green schist type. A possible answer to this objection may be found in the fact that, notwithstanding a rather intimate acquaintance with the Grenville series in both northern New York and in parts of Canada, the writer has nowhere else seen the counterpart of this green schist series. It is in rather close association with the Picton granite, which was richly supplied with mineralizing agents and is everywhere cut with numerous dikes from this granite, so that its peculiar characters are thought to be largely, or wholly attributable to this contact action, and thus explained as due to these local conditions. If this be not the explanation there seems no alternative but to regard the two thick limestones as separate beds, thus largely increasing the thickness of the section already great. If the structure is here correctly interpreted, a thickness of at least 20,000 feet is indicated for the Grenville of the district, and this is a conservative estimate. If the structure is not synclinal this thickness must be nearly doubled.

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Road metal quarry in Grenville limestone at Theresa near the falls. The limestone bed is a thin one in the general schist series and the quarry face is down the dip, here 75°. At the upper part of the cliff is Potsdam sandstone with irregular contact with the limestone, and showing one of the depressed pockets characteristic of these contacts, filled with weakly cemented calcareous sandstone. H. P. Cushing, photo, 1907

calcite. Toward the edges, however, the rock becomes much less pure, and at times the same thing happens in the near vicinity of the igneous intrusions, large and small, which repeatedly cut through it. This is by no means the invariable rule however. In the case of the thin limestone bands which occur in the general schist series [pl. 2] there is much less pure limestone, since these bands show the same impure borders as does the thick belt, leaving only a small central thickness of the purer rock. In this pure rock occasional graphite scales, flakes of brown mica (phlogopite) and occasional small crystals of white pyroxene (diopside) are the usual accessory minerals and in very small amount. Others occur, but very sparingly. These rocks must originally have been extremely pure limestones, slightly contaminated with organic matter, which now appears in the form of graphite.

The impure limestone of the area is owing to two distinct causes. Certain thin bands of impure limestone in the schist series, and the impure borders of the otherwise pure bands seem unquestionably owing to original deposit as shaly or sandy limestones, forming gradations between the pure rock and the overlying and underlying shales and sandstones. Hence on recrystallization a much smaller percentage of calcite and a much larger one of other minerals has resulted. The other cause is the interaction of the limestone with igneous rocks, producing what are known as contact rocks, in which certain added ingredients are supplied to the limestones from the igneous rocks and react with the limestone to form minerals which thus have a mixed origin. Such contact rocks are thus limited to the near vicinity of the igneous rocks.

The two most common kinds of impure limestone of the first type in the region are the quartzose limestones, and the pyroxenic limestones. Much of the marginal limestone seems to have been sandy, and even to have contained thin layers of fairly pure sandstone. This has recrystallized as quartz, partly in fine grain, forming a mosaic with the calcite, and partly coarser and in films and patches in the limestone. Each mineral at times contains inclusions of the other, they evidently recrystallized together, and the quartz evidently had the stronger crystallizing force. There is a considerable amount of limestone in the area which is a calcite-quartz rock, with little or no admixture with other minerals.

Even more common is the pyroxenic limestone, where the calcite is accompanied by a greater or less amount of a white or a light green pyroxene. This is prone to alter to serpentine, a dull green, greasy to earthy looking mineral, producing a mottled green

and white rock which is of common occurrence in the Grenville wherever known. In the writer's experience this is far from being true of the quartzose limestone which occurs in much greater force here than is customary.

Of the various Grenville rocks the limestones are much more yielding under compressive stresses than are the schists and quartzites, behave more like plastic and less like brittle bodies, and hence change shape more readily. As a result rocks which much resemble coarse conglomerates are a frequent feature in the Grenville limestone. Frequent dikes of granite traverse it, many of which are of slender width. Under compression these are brittle under conditions which are sufficient to cause flowage in the limestone, hence the dikes fracture, the separate fragments are somewhat shifted in position and limestone is squeezed in between them. The same thing takes place where thin bands of quartzite or of schist are present in the limestone, as is frequently the case. These fragments of granite, quartzite or schist weather less rapidly than the surrounding limestone, and hence project somewhat on weathered surfaces, with considerable increase in conspicuousness, and the separate fragments surrounded by calcite give an admirable mimicry of a conglomerate in appearance.

In addition to the normal white limestone frequent patches or streaks of gray or blue limestone also occur in association with it, which outwardly look much more like ordinary limestone. This is in line with the further fact that all the Grenville rocks seem somewhat less severely metamorphosed than is the case with the equivalent rocks to the eastward. Even the white marble has at times a grayish or bluish cast, and does not average as coarsely crystalline as the eastern Grenville limestone. On the other hand limestone of these characters is commonly not so pure as is much of the white limestone, and these gray or blue portions often occur in such situation as to suggest that they are contact effects of igneous rocks on the white limestone. In some instances certainly the white limestone changes to gray adjacent to an igneous rock mass of good size, and in others gray patches in white limestone occur in direct contact with granite dikes, an unlikely situation if they are really less metamorphosed portions of the white limestone. It is also true, however, that some of the gray limestone is very pure, that in some places it has no discoverable nearness to any igneous rock, and that in general the contact action of the igneous rocks of the district upon the limestone has been but slight, though with local exceptions to this statement. With such arguments in

mind it has seemed to the writer as though the weight of the evidence were in favor of the view that at least some of the gray and blue limestone was representative of the white in less metamorphosed condition, and if some, then likely all.

Nowhere else in northern New York has the writer met with Grenville limestone of this fine grained, darker colored type. A comparison is at once suggested with the district in Ontario recently described by Adams who has shown that a similar, though better marked change comes over the Canadian Grenville limestone when followed westward, a local development of bluish limestone in thin bands within the coarser white limestones.[1] The evidence seems to indicate that we have here in New York the first glimpses of a similar tendency.

The consideration of the contact effects which the various igneous rocks have had upon the limestones is deferred until the igneous rocks themselves have been described.

Quartzites. There are two belts of ponderous quartzites in the region, one on Wellesley and Grindstone islands, and the other in the district east of Redwood (Alexandria sheet). In both cases the quartzite is interbanded with various schists and amphibolites, in highly folded condition, so that the number of quartzite beds is uncertain, and whether there is more than one massive, thick quartzite can not be positively stated. There is certainly a considerable number of thinner bands. Unless our interpretation of the structure is wholly at fault, these two belts represent lines of outcrop of the same geologic horizon, and form the youngest rocks of the series exposed in the district. In addition to this main horizon there are also frequent quartzite bands found in the general schist series, and thin bands even occur at times with the limestones. The more prominent of such bands are indicated upon the maps.

The ponderous quartzites are the most resistant rocks of Precambric age in the region, and since they are interbedded with schists which are far weaker, the districts where they outcrop are quite rugged topographically, as Smyth pointed out 10 years ago. The quartzite ridges tower abruptly above the narrow valleys eaten out along the schists.

Since the rock is an altered sandstone, recrystallized under heat and pressure, and since sandstones often range in composition from a high degree of purity to those which are quite impure, either shaly, or calcareous, it is but natural to find much variation in the rock from place to place. The thick bands are chiefly constituted

[1] Adams, F. D. Jour. Geol. 16:623–24.

of massive, coarsely crystalline quartz, running up to as high as 90% of the rock, though feldspars and accessory minerals are always present. The thinner quartzite beds are generally more impure, though containing layers of coarse, massive, quite pure quartzite. The impurer beds are often well foliated, consisting of alternate films of pure quartz and of other minerals, the former very resistant to the weather, the latter less so, so that on the weathered surfaces the contortions and puckerings of the complexly folded schist series are much more perfectly displayed than in any other rock type of the region. They are often very close jointed, especially near granite, weathering out into small blocks [pl. 3].

Much of the quartzite of the district is more or less permeated with brown, iron-stained spots, due to the weathering out of some mineral with iron in its composition. These spots vary greatly in abundance in different occurrences and different layers, and may have a fairly uniform distribution, or, in the foliated varieties, be confined to the films containing other minerals than quartz, giving a brown and white, banded rock. In some cases, notably those of the first type, the mineral removed seems to have been pyrite, a mineral of consistent occurrence in the quartzite; in other cases it seems to have been pyroxene, though even here probably oxidized pyrite was responsible for most of the yellow, iron stain.

In texture the rock shows great variation, ranging from the very coarsely crystalline, glassy rocks, down to varieties which have a finely granular make-up.

Next to quartz, feldspars form the most prominent mineral constituent, orthoclase, microperthite and oligoclase all occurring. Much variation in relative amounts of the two mineral groups is shown, but in the great bulk of the rock, quartz is in excess and usually greatly in excess. In some varieties white to light green pyroxene appears in quantity, when the feldspar retreats. There is considerable of such quartz-pyroxene gneiss in the region, the quartz usually constituting 75% of the rock. Light brown mica (phlogopite) is sparingly present in much of the quartzite, and some varieties become quite micaceous. Pyrite is a frequent mineral, as has been stated. Zircon and titanite are nearly always present, and at times fine needles of rutile are abundantly included.

Here and there in the region rocks are found which present a puzzling half way stage between quartzite and granite, so that they are likely to be classed, now with one rock, and again with the other, according as the observer comes upon them from quartzite, or from granite. In all cases where the relations could be worked

Plate 3

Grenville quartzite of the much jointed type showing its characteristic weathering. The Potsdam lies just above but shows poorly in the view. Locality near the south margin of the Alexandria Bay quadrangle, nearly 1 mile south of Crystal lake, by the roadside. H. P. Cushing, photo, 1907

out such rocks either occur along granite-quartzite contacts, or else are included in granite. They are apt to show close set, block jointing, like the quartzite. They have been found only in association with the granite gneiss. The field evidence seems to us strongly indicative of the fact that these are really intermediate rocks, in the sense that they represent quartzites in various stages of granitization; that the quartzite is being permeated, soaked and even digested by the granite. The character of the intermediate rock, the shading of the two into one another, and the field occurrence of the intermediate stages, all point to this conclusion, and seem incapable of explanation on any other hypothesis.

Amphibolites. The name amphibolite is a convenient, comprehensive term for a group of rocks of gneissoid habit and dark color, composed essentially of hornblende and feldspars, with often considerable amounts of biotite or pyroxenes, and with accessory minerals of which magnetite is easily chief, and quartz and garnet of frequent occurrence. In respect to origin, the rock has long been a puzzling one since apparently identically appearing amphibolite might be produced by metamorphism from either igneous or from sedimentary rocks of the proper character. In a multitude of localities in the Adirondacks it has been shown that gabbro intrusions (whose character and origin is rendered certain by a core of practically unchanged rock) are largely changed over into amphibolites, every step in the process being open to inspection. Similar relations have been shown in many localities in all continents. Also in the Adirondacks, wherever the Grenville series is exposed, bands of amphibolite of varying thickness are found so definitely interstratified with other Grenville rocks of unquestioned sedimentary nature, that there seemed no escape from the conclusion that the rock must have resulted from the metamorphism of a sediment; and amphibolite of such origin is equally of world-wide distribution. In addition it has recently been shown by Adams that amphibolite can also be produced on a large scale by the contact action of granite on limestone. Here are therefore three different modes of origin, and the rock may be either igneous, sedimentary, or a contact rock. Each occurrence of the rock must therefore be studied by itself, in so far as its origin is concerned. Amphibolite of all three types is present in our district.

Within the mapped area amphibolite has not the bulk and importance that it has in much of the Precambric district adjacent. There is much of it present as inclusions in the granite gneiss bathyliths and stocks, inclusions of much variation in size and in

abundance. Frequent bands of it occur within the Grenville series, but these are usually of no great thickness. There is but little of the rock present to which an igneous origin may be definitely assigned. There are small areas of such rock in the district north and northeast of Theresa, where a somewhat more heavily bedded amphibolite occurs, which holds much pyroxene in addition to the hornblende, and which seems to definitely cut the limestone with which it is associated. There are, however, amphibolite bands interstratified with the same limestone, and the mass has been severely deformed, with the production of flow in the limestone and the fracturing of the amphibolite into blocks, making one appear to cut and be included in the other, but this does not seem to be a case of the sort. In our experience amphibolites which result from the metamorphism of gabbro, usually contain pyroxene in quantity, while those originating from calcareous shales are more apt to be micaceous and lack the pyroxene, but this is far from being an invariable rule, and is only suggestive of origin, not demonstrative.

The amphibolites interstratified within the Grenville series, and regarded as metamorphosed sediments, calcareous shales or something of that sort, are mostly quite finely and evenly granular rocks, which have wholly recrystallized, and vary from very solid looking, dense rocks in which mica is but sparingly present, to very schistose, highly micaceous rocks, which rapidly break down under the weather. In most of these orthoclase feldspar is apt to predominate over plagioclase, and much of the rock contains some quartz, the micaceous varieties often considerable. The manner in which the variations appear is itself highly suggestive of metamorphosed sediments which differed somewhat in character from bed to bed. Some of the rock contains garnets, in some cases reaching large size, but they are exceptional rather than the rule.

The amphibolite of contact origin will be discussed under the general topic of contact rocks.

Schists. Under this heading are included a large number of rock types, so many that it seems hopeless to attempt to describe all, or many of them. No doubt they have diverse origins. Some of them quite certainly owe their present character to contact action, and no doubt contact action of varying kind, and in varying degree, is in large measure responsible for the great diversity of the group. Some of the rocks grouped here are no doubt igneous, and in their character distinctly suggest such an origin, though the proof is difficult to obtain.

A very common variety of Grenville schist, the so called " rusty

gneiss" with its characteristic yellowish tinge on weathered surfaces, is but sparingly present in our area here. In the district east of Redwood it occurs somewhat, as it does also to the northward of Theresa. It is a quartzose gneiss, usually containing the mineral "sillimanite" and holding pyrite in quantity, the easy decomposition of which is chiefly accountable for the weakness and the color stain of the rock.

There are reddish, acid gneisses which, so far as composition goes might be either original granites, or shaly sandstones. There are black and white gneisses, which are feldspar-pyroxene-quartz gneisses. There are very granular, dark reddish, weak, microperthitic feldspar-hornblende gneisses; gray, feld-spar-hornblende gneisses, holding much pyrite and titanite; there are leaf-quartz gneisses, the quartz in coarse spindles or lenses, and with little other than feldspar in addition; evenly granular, white, spotted gneisses which are microperthite-quartz-hornblende rocks; garnetiferous, quartz-biotite gneisses, with but little feldspar and a lot of pyrite; quartz-feldspar-phlogopite gneisses with graphite; gneisses which somewhat suggest metamorphosed volcanic tuffs, though in no case has it been possible to demonstrate such an origin for them. Many of the rocks contain calcite, which at times has resulted from alteration and at times suggests itself as an original constituent. Graphite is a frequent mineral in many of the schists.

Nowhere in the district has a rock been found which at all suggests the greenstones of the Keewatin formation.

Belts of badly altered rock, considerably impregnated with iron, so as to constitute lean iron ore, occur within the Grenville schist belts, striking with the belt and apparently behaving like an integral part of the series. Fragments of one such belt are found in the granite of the Alexandria bathylith near Cranberry creek, and a prominent belt occurs east of Redwood, especially along the north side of Millsite lake. The rock is exceedingly weak, earthy looking, either red, or yellow brown in color, and has a considerable local use for road metal. It is so thoroughly altered that it is almost impossible to get any clear notion of its original character being simply a mass of clayey, alteration products, with considerable calcite, and the whole impregnated with hydrated iron oxid, chiefly the red oxid. There are fresher streaks and bunches here and there which appear to be granite gneiss. None of the so called "serpentine" rock, which is generally associated with the similar, but richer, belt of iron ore which runs through Antwerp

and Rossie, just east of our map, has been noted here, but with that exception there is a strong resemblance in the material.

Igneous rocks. *Gneissic granites* (*Laurentian*). There are two extensive (bathylithic) masses of granite gneiss in the district, both of which are only in part within the mapped area. The western end of what we have called the "Antwerp bathylith" is exposed on the Theresa quadrangle, disappearing westward under a Paleozoic cover. The Alexandria bathylith, on the mainland and islands of the Alexandria quadrangle, seems of smaller size but also disappears under a Paleozoic cover, both eastward and westward, and passes across into Canada as well. There are in addition numerous smaller masses. It is highly probable that all are connected underground, and represent the upper portions of a great, underground mass of granite, underlying all of the Grenville of the district, except where cut away by the later intrusions.

That this granite came to its present resting place after the Grenville was deposited was pointed out by Smyth 10 years ago, and is shown clearly in a host of exposures. Dikes without number run out from the granite masses into the Grenville rocks, the granite is everywhere full of included fragments of the Grenville, and along the contacts between the two sets of rocks, the Grenville rocks have plainly been modified by the contact action of the intrusive.

The general rock is a quite acid, red granite, composed chiefly of feldspars (microperthite, microcline and oligoclase) and quartz, with small amounts of mica (both biotite and muscovite) and magnetite, and with zircon, titanite and apatite as accessories. Such rock does not appear especially gneissoid, though usually of rather fine and even grain, but in thin section it invariably shows much crushing, and a considerable amount of recrystallization. The rock is everywhere cut by its own aplite, pegmatite and quartz dikes, some of which are much coarser grained, as usual. Many of the granite dikes which penetrate the Grenville, especially the limestones, are coarser grained, and less mashed than the general rock.

In a minor way the rock of the bathyliths is quite variable, and that in two main ways, one apparently representing original variations in the rock, and one owing to relative abundance of inclusions and the effect of the granite on them. The rock varies from one which is almost wholly constituted of feldspars and quartz, to one which contains several per cent of mica, which

thus becomes a conspicuous constituent. The rock changes from deep red through lighter shades to nearly white. It varies also much in texture, from throughly solid looking, crystalline appearance to varieties which weather to a sugary, granular aspect.

As usual in the Laurentian, inclusions abound, and as usual the bulk of these are of amphibolite. Quartzite inclusions also occur, but infrequently, limestone inclusions never. The amphibolite inclusions are found everywhere but always most abundantly near the margins, where they abound. In fact a sharp boundary line between the granite gneiss and the adjacent Grenville rocks can not be drawn. In passing from granite to sediments the inclusions show steady increase in number until they come to constitute 50% of the rock, beyond which we find sediments cut by granite dikes rather than granite holding inclusions of sediments. This reduces boundary mapping to a matter of estimating equality or inequality in amount of the two rocks, or in drawing a boundary where no real one exists. An attempt, however, has been made to indicate, by convention, on the maps, the actual state of things found in the field.

The granite dikes usually represent the extreme acid state of the rock. The main mass averages less acid, chiefly because of the inclusions and of the attack of the granite upon them. In its preliminary stages this usually takes the form of an injection of the granite in thin sheets along the foliation planes of the amphibolite, the so called "lit-par-lit," or leaf type of injection, producing a banded rock of alternations of igneous and sedimentary material. Then, here and there, the granite breaks out from the foliation planes and spreads through the rock adjacent, forcing its grains apart by the injection of a thin film of granite between. This process becomes more and more pronounced, until much of the rock is broken up into a granular mosaic of particles cemented together by granite films, producing what may be called the mosaic type of injection, as distinguished from the leaf type. A fine example of injection of this type is shown in plates 4 and 5. The injected rock is not amphibolite, but is green schist, a closely related rock, and the type of injection is identical. As a further stage, in both types of injection, the sharp boundaries become blurred, and this shading of the two rocks into one another becomes more and more prominent until finally rocks result which seem unquestionably to be due to the complete digestion of the amphibolite by the granite, gray gneisses of distinctly intermediate composition. As would be expected

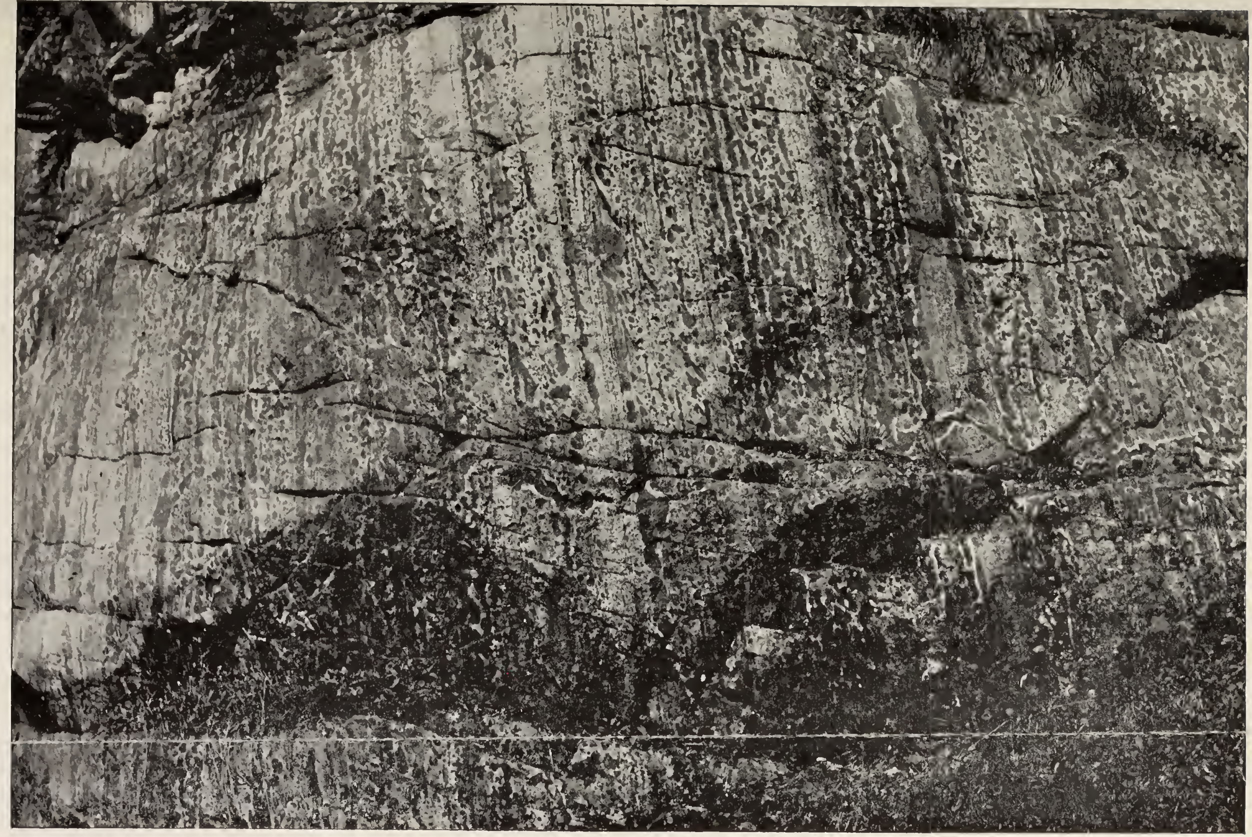
these more advanced stages are usually found in the case of inclusions away from the near vicinity of the border.

We have not, up to the present time, definitely classed any of the granites of northern New York as of Laurentian age. Just across the border in Canada however, where the rocks are identical, this term is definitely applied to the granite gneiss of the bathyliths which invaded the Grenville series from beneath, broke it up into disconnected belts and patches and destroyed all trace of its floor. The absolute identity of the rocks and their relations, leads us to apply the name here to the granite gneiss bodies with much confidence in the wisdom and propriety of the correlation. Whether these Laurentian granites are recognizable, however, over any considerable part of the Adirondack region, in distinction from granites of later date, is a much less certain matter, though we believe it to be the case. It is thought for example that what we have called the Saranac gneiss in Clinton county, and the Long Lake gneiss of that quadrangle, are in all probability of Laurentian age.

Theresa syenite. This comparatively small intrusive mass lies to the southward of Theresa, in a valley floored by Precambric rocks, but walled in by Potsdam on all sides It is somewhat less than 2 miles in length and with a breadth of less than half a mile, so far as the exposures go; at the south it may have greater breadth underneath the Potsdam.

The general rock is of medium coarseness and granitic texture, though always with evidence of mashing and granulation, and of gray to greenish color. Most of it is chiefly made up of feldspars. It resembles in high degree the common greenish, augite syenite of the Adirondack region, is unhesitatingly classed with that, and is the only representative of that rock type within the mapped area. Like it, this rock is quite variable, becoming red and granitic looking on the one hand, and more basic with increase of black minerals on the other. Near the border some varieties become feebly porphyritic.

Microperthitic feldspar is always the chief constituent of the rock. Some oligoclase is always present. Quartz varies from some 15% in the more granitic, red varieties, down to complete absence. Augite is the most prominent black mineral in the ordinary rock, with biotite usually and hornblende sometimes sparingly present; magnetite, apatite, titanite and zircon are the chief accessories, the apatite usually quite prominent, another feature which the rock has in common with the general Adiron-



Grenville green schists intimately cut by granite. Forsters landing, by roadside not far from spot shown in plate 1; looking east. Hight shown is about 10 feet. The schist shows dark and the granite white. The granite is injected along the foliation planes of the schist and then ramifies out into the intervening space, separating the schist into mosaic blocks or grains. Only the coarser of these show well in the view but the broader white bands are the same mixture on a small scale. This is regarded as the initial step in the process of the digestion of the schist by the granite. H. P. Cushing, photo, 1908

Upper figure. Hand specimen of the green schist, injected by granite, shown in plate 4. The central band here is one of those which appear as uniform, white bands in that view; here shown to consist of schist thoroughly and minutely broken up by, and inclosed in the granite.

Lower figure. Hand specimen of sheared, banded, acid gneiss from near the shore of Wellesley island, due west of Alexandria Bay. Shearing has produced numerous, slight faults, the shear planes are solidly welded up by secondary minerals, and dikes of the Picton granite cut across these, these of course not showing in the specimen. H. P. Cushing, photo

dack syenite. In the most basic variety seen, these dark minerals constitute no more than 15% of the rock, the remainder being feldspar with a little quartz.

Granting the equivalence of the rock with the general augite syenite, its age is rather definitely fixed as one of the great intrusives of the region, younger than the Grenville and the Laurentian granite, and also younger than the anorthosite intrusion. Since this latter rock is not represented in the district, and the only direct evidence of age seen in connection with the Theresa syenite is that it cuts the Grenville, this additional evidence is welcome.

Alexandria syenite. The intrusive mass of syenite called for convenience by the above name, since nearly the entire mass is in Alexandria township, lies west and north of Redwood, with a major axis of nearly 6 miles, and with a greatest breadth of nearly 2 miles; this on the supposition that but a single intrusion is here represented, as is believed to be the case. It is possible that two intrusions are here in which case the southern one fourth must be separated from the rest.

Much of the rock is considerably crushed, granulated and recrystallized, converting it into an augen gneiss. The size of the augen, many of which are a half inch long, bespeaks either a very coarse grained rock originally, or a porphyry, the latter being regarded as most probable. These coarse augen gneisses are chiefly peripheral, and mostly at the south end of the mass. Centrally, considerable cores of much less mashed rock remain which, while of medium coarseness of grain, do not approach the coarseness of the augen. The bulk of the rock is an augen gneiss with small augen, and it may be that the coarse augen gneiss at the south should be separated from the remainder; the two seem, however, to grade into one another, and no evidence that one cut the other was found, except that in a few localities the coarse augen gneiss is cut by dikes of fine grained red granite. These seem rather acid for dikes from the syenite. It is possible that they are stray dikes of Picton granite.

The least mashed cores show a rock of granitic texture and medium grain, composed chiefly of a reddish feldspar and black hornblende, the latter in sufficient quantity to give some of the rock a strong resemblance to a diorite. These least gneissoid portions always show much mashing, when seen in thin section, the feldspars being granulated at their margins, and the hornblendes fraying out into biotite scales. This change increases until

finally we get a rock in which but few unmashed feldspar centers remain, the hornblende has entirely disappeared, and the rock is a finely granular aggregate of feldspars, mica scales, and some quartz.

Of accessory minerals, apatite and titanite are prominent, the former being abundant for this mineral, and of good size, the latter usually rimming the magnetite, as well as occurring away from it. The feldspars comprise microcline, microperthite and plagioclase (oligoclase-andesine), with the latter somewhat in excess when the plagioclase in the microperthite is included with it. The quantity of the two, however, is not far from equal in most cases. There is little or no quartz in the least mashed rock, and the quantity steadily increases in the gneissoid varieties. Some of this increase is certainly due to reactions during recrystallization since quartz commences to appear with the appearance of biotite. On the other hand the rock varies somewhat in acidity and some of the quartz is unquestionably primary.

The coarse augen gneiss at the south has much the same mineralogy as the remainder, though more quartzose and acid, approaching a granite in composition. Smyth holds the view that it is a separate intrusion from the main mass of the syenite, and older, having noted an exposure in which the syenite appeared to cut the augen gneiss. We did not have the good fortune to observe any such exposure, hence his positive evidence must outweigh our lack of such. Chemically also the augen gneiss is much more acid than the syenite, being remarkably like the Picton granite in composition. If the two are separate, the augen gneiss is the older, and both are younger than the Laurentian, while the Picton holds inclusions of the augen gneiss.

This syenite differs considerably from the usual type of syenite of the Adirondack region, represented here by the Theresa syenite, both in general appearance and in mineralogy. Analyses and more detailed description will be given in a later section of this report. It is more gneissoid, giving the appearance of greater deformation than the Theresa syenite, and hence it is tentatively inferred that it is somewhat older than that. The appearance may however be entirely deceptive, since the one rock gives rise to abundant mica when deformed, and the other furnishes little or none, nor any other mineral which promotes foliation. Hence the same amount of deformation would produce a better foliated rock in the former case than in the latter, a rock which would appear more greatly deformed.

Picton granite. This is the latest, most extensive, most interesting, and most important of the intrusives of the region. It is named from Picton island (called Robbins island on the map) where it is most extensively quarried. It is, however, best and most extensively exposed on Grindstone island and would have been named after it except for the fact that the whole name was too long, and the term "Grindstone granite" possibly misleading. It is extensively exposed also on the west end of Wellesley island. Abundant dikes of it appear on the mainland of the Alexandria sheet, cutting the Alexandria granite gneiss and the Grenville schists, but the main mass falls short of reaching the shore. It does reach the mainland on the Clayton sheet, however, judging from the exposures of the Precambric inlier up French creek, and may have wide extent here under the Paleozoic rocks. Across the border in Canada it seems to have large extent, though it has not yet been differentiated from the Laurentian in mapping. If, however, we are correct in correlating the granite at Kingston with this rock, a bathylith of considerable extent is implied.

The general rock is a rather bright red granite of quite coarse grain. It varies much in this respect however, and much of the border rock is of much finer grain, as is also true of the general run of the dikes which radiate out from the mass. To a certain extent this diminution in apparent size of grain is due to mashing, but certainly the major part of it is a primary difference.

Red feldspars (microperthite, microcline and oligoclase) constitute 75% or more of the rock. Considerable quartz is usually present and is frequently characterized by a slightly bluish cast, which makes a helpful diagnostic feature of the rock. Hornblende and biotite are sufficiently abundant to show prominent black spots in the otherwise red rock. In the finer grained border varieties and dikes, these black minerals retreat, quartz becomes somewhat more prominent, and the rock appears more acid. The general rock, however, does not impress one as a particularly acid rock for a granite, and this impression is borne out on analysis (given in a later section).

The rock of the inlier to the south of Clayton, and that at Kingston are correlated with this granite with some reserve. The Kingston rock is a red granite of almost identical appearance with this, agrees closely in composition, and the only hesitancy felt in the matter is owing to the distance separating the two areas. In all likelihood the rock can be carried across on

the Canadian islands to the mainland and thence west to Kingston, but until this has been done some reserve must be felt in making the correlation. The rock near Clayton differs in containing no quartz, and in being somewhat more mashed than the generality of the rock. It is in fact an acid syenite rather than a granite. Otherwise the two are exceedingly alike, and since the granite itself is low in silica for a granite, approaching a syenite in that respect, but slight variation is needed to cause the disappearance of the quartz.

It must be borne in mind, in inspecting the maps, that the boundaries drawn between the Picton granite and the Laurentian are in the highest degree conventional. They are of the same vague sort as those between the Laurentian and Grenville, but even more vague than those because of the similarity of the two rocks. The fine grained dikes of the Picton are exceedingly like the acid dikes sent out from the Laurentian, and it is almost an impossible matter to tell which rock is in excess. On the other hand the maps do show the chief areas of the two rocks, bring out the fact that the one is younger than the other, and show their relative distribution and extent as accurately as possible in rocks of this kind.

That the rock is the youngest of the intrusives of the region is indicated in several ways. It shows less sign of mashing than do any of the others, that is its unmashed central core is relatively much larger. Besides its abundant inclusions of various Grenville rocks it contains also frequent masses of granite gneiss of Laurentian type, and sends abundant dikes into similar rock where bordered by it, as it is locally on both Wellesley and Grindstone islands; and also it contains inclusions of an augen gneiss which is absolutely identical in character with the rock of the Alexandria syenite. Such age for the rock then seems to us in the highest degree probable, though it falls somewhat short of actual demonstration.

Dikes of the granite are thought to range widely in the rocks east and south, though no attempt to indicate this upon the areal maps has been made. They are believed to be numerously present in the green schist belts of the western part of the Alexandria quadrangle, and also in the granite gneiss of that quadrangle. Even as far east as Alexandria Bay broad dikes of acid, usually fine grained, granite occur abundantly, cutting the granite gneiss all to pieces, and often inclosing sharp inclusions of it. We have never seen inclusions of this type held abun-

dantly in the aplite dikes of the granite gneiss itself, and regard the granite of the dikes as likely Picton.

The contact relations of this rock with those adjacent are of much interest. It was apparently richer in mineralizing fluids than any of the other intrusives, and gives rise to interesting contact rocks, to be described in the succeeding section. But the field relations are also most important and interesting.

While mapping Wellesley and Grindstone islands it quickly caught our attention that the abundant inclusions with which the Picton granite is everywhere charged were arranged in belts, that is, along a given line the inclusions were all quartzite, along an adjoining line they were all amphibolite, along another nothing but granite gneiss inclusions appeared. It was also seen that these belts had northeast-southwest trend, concordant with the general rock strike of the region, and that further the individual inclusions to large extent retained their original orientation and dip, notwithstanding the intrusion. Our strikes and dips, read on the rocks in the field, gave absolutely concordant results as we passed from one inclusion to another, results also concordant with the readings obtained on the same rocks beyond the reach of the intrusion. We were able to map the original belts of Grenville quartzite and schist, and the intrusions of Laurentian granite gneiss, as accurately as though the Picton granite was not present, so little had they been disturbed by the intrusion. An attempt has been made to bring out these facts upon the geologic maps. We could only account for the phenomena on the assumption that we have exposed here the very roof of this portion of the bathylith, the abundant inclusions representing masses but just loosened from their original place, not greatly sunken, and preserving unimpaired their original orientation. If this be the correct interpretation, the locality furnishes a fine illustration of the general phenomenon.

Other intrusions. While the above furnish the only examples of intrusions of considerable size in the region, there are many others of small size, mostly too small to map, and which it seems hardly worth while to describe in detail. These are chiefly of granite gneiss, and are regarded for the most part as of Laurentian age, and as representing comparatively small upward protrusions from the general roof of the great mass of Laurentian granite gneiss which is believed to underlie the entire district, except where broken through by the later intrusions. A good

illustration is that of the granite gneiss in the extreme southeast corner of the Alexandria sheet, which forms a wonderful cliff along the Indian river.

In quite a number of localities syenitic rocks were found, always of trifling extent, and with field relations wholly indeterminate.

At the west end of the upper bridge at Theresa, is a small intrusion of gabbro, which is but little mashed, and has some features of interest in that it recalls the anorthosites and gabbros of the general Adirondack region, and is the only representative of these rocks seen here. It is a dark colored rock, showing numerous, glittering, lath-shaped feldspars up to an inch in length, on broken surfaces. It is made up of feldspar (labradorite), augite, hypersthene and hornblende, with considerable magnetite, and a little pyrite and apatite as accessories. The feldspar constitutes from 60 to 70% of the rock. In composition therefore it is distinctly a gabbro, though with more abundant feldspar than the usual Adirondack gabbro. Yet, in spite of the coarsely lath-shaped feldspars the structure is more nearly that of a gabbro than a hyperite, recalling in this respect the anorthosite-gabbros farther east.

Diabase. Cutting all the other Precambric rocks of the region, occasional dikes of trap rock are found. The fact that they cut all the other rocks shows that they are younger, but it can also be shown that they are much younger than the other igneous rocks, though nevertheless older than the Potsdam sandstone. They are found only in the form of dikes, which are lava-filled fissures that in general represent plugged channels of ascent of the molten rock, leading downward to some source of supply of the material, and tending upward toward the surface. The dikes have chilled borders, showing that the inclosing rocks were comparatively cool and hence at no great depth beneath the surface at the time of solidification. Furthermore they show no sign of having undergone the kind of deformation which all the other igneous rocks have experienced in greater or less degree, a kind which takes place only at considerable depths. Since the diabases cooled much nearer the surface than the granites and syenites, a long time interval of surface erosion during which a considerable rock thickness was worn away from the surface, must separate the two.

In the district mapped these dikes have a somewhat unequal distribution. They are most abundant on Grindstone island, seven having been noted there, mostly of large size, none of them less than 20 feet wide, and ranging from that up to 100 feet in the case

of the dike numbered 1 on the map. Two have been found on Wellesley island, the wider of which measures 30 feet. Seven have been found on the mainland of the Alexandria sheet, in rather widely scattered distribution, and in general much narrower. None have been observed on the Theresa sheet. Smyth has described them as abundant on the Canadian mainland and islands in the vicinity of Gananoque, hence in the near vicinity of Grindstone island, which would seem to have been the chief center of activity. For petrographic details the reader is referred to his account which, though based on Canadian material, also describes these accurately.[1]

The dikes trend in various directions, from northwest around through north to northeast. Smyth states that those seen around Gananoque trend chiefly to the north, and were all cutting granite. It is to be noted that all those trending northeast, in our district here, are cutting Grenville rocks with general northeast strike, while all the dikes cutting the igneous rocks trend north or northwest. This is also true of two of the dikes cutting the Grenville, but in both cases the Grenville is in comparatively small bulk, and entirely inclosed by igneous rocks. The dike directions are therefore apparently determined by preexisting structures in the rocks, by the strike in the Grenville, and by a joint set in the igneous rocks. Small masses of Grenville rocks did not suffice to change the direction of dikes passing across them, the igneous rocks here being the determining factor.

Though they give no evidence of having been severely deformed, yet the rock of the larger dikes does show evidences of considerable pressure. Many of the feldspar crystals are distinctly bent, and both the feldspar and augite of the rock shows evidence of strain by their undulatory extinction. In this respect they contrast with the diabases of the eastern Adirondacks, which show no such strain effects. The eastern dikes also have chiefly east-west trends, differ somewhat in mineralogy, and are more numerous and widespread; and are also separated from this area by a wide region in which such dikes are absent. We seem here therefore to be dealing with a wholly different center of igneous activity, and a much less extensive one than that farther east.

Owing to their size and comparative freshness these dikes have a potential value in the region as a comparatively accessible source of good road metal.

Contact rocks. The contact effects of the igneous rocks upon the Grenville sediments, and vice versa, may be grouped under three

[1] N. Y. Acad. Sci. Trans. 13:209–14.

categories, effects produced upon the igneous rocks themselves, effects of the igneous rocks upon the sediments whereby rocks of intermediate composition are produced, and effects produced upon the sediments by the injection into them of fluids from the igneous rocks, fluids rich in mineralizing agents, and of quite different composition from the general mass of the igneous rock.

Bleaching of granite by limestone. In the early stages of the work it was noted that, while granite dikes and knobs of all sizes were of frequent occurrence, cutting the Grenville limestone wherever exposed, in all cases the granite was white, nearly as white as the limestone in fact. The granite of the bathyliths is, however, uniformly of red color, as are also the dikes in rock other than limestone. This led to search for limestone contacts along the margin of the Antwerp bathylith and of the smaller granite intrusions of the Theresa sheet, when it was found that in every case the margin of the granite, adjacent to the limestone, was turned white. It also proved to be the case in subsequent work that whenever, in passing over granite country, a whitening of the rock was observable, directly beyond crystalline limestone was sure to be found. It also was found that the general granite of the Antwerp bathylith had had singularly little contact effect upon the limestone, pure, unchanged limestone lying directly in contact with the granite in most cases, and that the dikes also had had no contact effects, so that the rather unusual condition was presented of granite-limestone contacts in which the granite was the rock showing contact effects, not the limestone.

Study of the white granite, both chemically and in thin section, affords no explanation of the change. The white granite is in general somewhat more acid than the red, but that is believed to be nothing more than an expression of the general fact that the dikes which radiate out from the bathyliths are more acid than the main mass, whether they be red or white (they are usually red in all rocks except the limestone), and that the granite also is apt to become more acid near the margins. A little tourmalin is sometimes developed in the granite where white, but it also developed elsewhere. The change seems to consist merely in a decoloration of the feldspar, changing it from red to white; that of course on the assumption that the red color of the feldspar is original and not a later coloring due to slight alteration. In that case, however, it is difficult to understand why both feldspars, of the white granite as well as of the red, should not have undergone the alteration; this seems in fact so highly improbable, that we seem justified in regard-

ing the color as beyond question original. The red color which so many feldspars possess is usually ascribed to ferric oxid, though in general without any definite proof in the matter. In such case the loss of color might be ascribed to simple reduction of the iron, but what reducing agent the limestone might furnish is a difficult problem and greenish, rather than white, feldspar would likely result. Analyses of both white and red granites are given on a later page, where the matter will be somewhat further discussed. The chemical differences between the two rocks are but slight, and we are in doubt whether in any recognizable respect they are due to influence of the limestone. The field relations are, however, perfectly clear, and susceptible of no other explanation.

Mixed rocks. Rocks which seem definitely of intermediate composition between the intrusive and a sediment, to be due to the intimate penetration and final digestion of the latter by the former, and which show all stages in the process, occur as the result of action of granite upon amphibolite and upon quartzite. In the former the action is chiefly seen in the case of the amphibolite inclusions which so abound in the granite gneiss, and which are found in all stages of being first penetrated by films of the granite and later slowly absorbed by it. The process has already been described; so has the gradation of granite into quartzite which is found in some localities and which seems only explainable on the assumption of production of a border zone of true mixed rock between the two.

Contact rocks. These, as here understood, result from the injection into the sediment of fluids from the igneous rock which contain only certain of its constituents instead of all, and which may, and often do, differ very materially in composition from the rock itself. The injection is apt to be more or less local, here much, there little, or none at all; the injected fluid may differ in composition at different points along the border of the igneous mass; the bordering rocks themselves differ from place to place, and finally the various igneous masses are quite sure to differ among themselves in the character of their mineralizing fluids. Since we have here three separate granite bathyliths, to say nothing of the syenites and smaller granite masses, and Grenville rocks of great variety of composition, the opportunity for contact action of diverse sorts is exceedingly good.

Green schists in Alexandria. Reference to the geologic map of the Alexandria quadrangle will show, to the south and southwest of Alexandria Bay, three northeast-southwest ridges of Grenville schists. These are cut out on the north by the granite of the

Alexandria bathylith, though there is a zone between the two in which exposures are poor and infrequent. They are separated from one another in part by tongues of Potsdam sandstone, and in part by low, marshy valleys in which no rock outcrops appear. The exposures, however, cover an area of several square miles, and extend to a distance of at least 3 miles from the edge of the bathylith. The schists are everywhere cut by dikes of granite, most numerously as the granite is approached. While chiefly of the Alexandria granite gneiss, it seems to us that dikes of the Picton granite are also present numerously, though it is difficult to arrive at certainty in the matter. Certainly they are present in the granite gneiss itself. Nowhere else in northern New York have we seen just this type of schists, except as occasional occurrences of small extent and bulk. We are disposed to regard them as contact rocks, produced by the action of the granite upon what were, prior to the intrusion, somewhat impure limestones. We are disposed also to regard the Picton granite dikes as especially influential in the action. It must be frankly stated, however, that there are certain difficulties in the way of this view, and they will be later summed up.

The schists are well banded and foliated and range from light to dark green, or greenish black, in color. They are usually of finely granular texture though these alternate with somewhat coarser grained bands. These latter show poorer foliation and are mottled green and pink in color. Narrow, dark red bands sometimes appear, due to subsequent infiltration of ferric oxid. At times the green minerals become scant, and the rock then has a light red to pink shade. Narrow bands of black amphibolite and of finely micaceous schist also appear, and an occasional thin quartzite band. But the bulk of the series is of green schist. Granite dikes and dikelets abound everywhere, cutting across or parallel with the bedding, in the latter case often forming a good injection gneiss. The dikes are of fine, granite gneiss, of coarse granite, of yet coarser granite pegmatite, or of quartz, the first most abundant.

In composition these green schists are essentially feldspar-pyroxene rocks, the latter of green color and responsible for the general hue of the rock. Actinolite is commonly present, and very abundant in some of the bands; it is the only amphibole noted in the schists, except in the occasional amphibolite bands. Epidote is often present, though far less common than the actinolite. Some layers hold frequent, small, light colored garnets. Small, scattered, black tourmalins occur throughout the rock in all exposures.

Small titanites *abound* in the rock, magnetite and hematite appear in varying quantity, with pyrite, apatite and zircon as other accessories.

Quartz is present in many of the bands but seldom in any great quantity and often wholly absent. The feldspar is in part microcline and in part plagioclase (andesine-labradorite); some microperthite is usually found also, and often much feldspar not characteristically marked.

In addition to the above minerals the rock nearly always contains calcite, and this in steadily increasing quantity as the distance from the granite bathylith increases. The rocks from the schist inlier in the Potsdam due east from Omar, average 20 to 25% of calcite; in the long ridge just to the north of this it occurs in large, though somewhat less amount; while in the ridge northwest of this, and nearest the granite, much of the rock shows but little calcite, only the coarser, mottled beds having it in quantity. The calcite is coarsely crystalline, in sharply bounded individuals, and clearly formed at the same time as the other constituents of the rock.

The mineralogy of the schists strongly suggests contact effects, the tourmalin, actinolite and epidote being especially suggestive in this respect, none of them being normal Grenville minerals, away from the immediate vicinity of igneous rocks. The green pyroxene also is an abundantly formed contact mineral in the Grenville, though not so distinctive of contact metamorphism as the others. These, with the constant presence of calcite, give an impression that we are here dealing with a limestone belt much changed by contact action, with the granite and pegmatite dikes which abundantly penetrate the series as the source of the mineralizing fluids. The fact that these green schists, though here present in great bulk, are not a usual member of the Grenville succession in the general region, also suggests a local cause for their presence. It would seem that a series so thick could not but occur repeatedly elsewhere were it an ordinary member of the general series. Similar rocks do occur in small bulk in the general schist series north of Millsite lake, but their small amount here but emphasizes the bulk of the other occurrence.

As opposed to this suggestion of contact origin, the breadth of the belt and the distance it extends from the granite margin, its general uniformity of character, whether in contact with a dike or at a considerable distance from one, whether near the granite margin or remote from it, (the only observed difference

being in the amount of calcite, and that a very slow and gradual change), seem more suggestive of regional than of contact metamorphism. On this view the belt would consist of original impure limestones and calcareous shales, metamorphosed to the pyroxene-feldspar-calcite combination, and with the tourmalin, actinolite and epidote alone due to the later contact action. While unable to definitely decide between the two, the first seems to us the more probable. It is possible that the granite is close in place underneath the whole belt. In our view, then, the belt is due to the contact action of an especial granite, its localization being thus explained, acting upon a limestone series of considerable thickness, and certainly somewhat impure at least, as shown by the bands of quartzite, amphibolite and mica gneiss within it. Part of the regular Grenville succession of the area consists of alternating thin beds of limestone, various schists and an occasional quartzite, and it would seem as if such a combination might well be turned over into a group like that of the green schists by contact metamorphism. This would be all the more likely if acted upon by two successive, granite injections as is supposed to be the case here, since dikes of Picton granite are believed to be present.

The coarse pegmatite dikes of the north schist ridge, which furnish well crystallized specimens of orthoclase and specular hematite, to be found in many mineral collections, have already been described by Smyth.[1]

Tourmalin contact zones in Alexandria. The Picton granite is found cutting Grenville quartzite and amphibolite, but no other members of the series, and the same is true of its *known* dikes; that dikes suspected to belong to it cut other members has just been seen. This granite seems to have been much more potent in tourmalin-forming capacity than any other granite of the region and its contacts with the Grenville on Grindstone and Wellesley islands are characterized by narrow tourmalinized zones which Smyth has clearly described, as follows:

Along their margins these dikes frequently show much black tourmalin and this is usually most abundant in the very narrow ones, in which the imperfect crystals of tourmalin interlock across the entire width. At the same time the schists along the contact become impregnated with fine, granular tourmalin, producing strips and irregular areas of a lustrous black rock. The remarkable feature about these contact zones in the schist is their extreme irregularity in form and extent, and their entire independence of the magnitude of the accompanying dike. A dike of granite a foot wide

[1] *op cit.* p. 194.

may have no contact zone, while a mere thread of granite a few feet distant, may be bounded on each side by a band of the tourmalin rock 2 or 3 inches wide. Again, the tourmalin, instead of forming a continuous band, appears in lumps and bunches of every conceivable shape, irregularly scattered along a dike, and sometimes extending several inches away, at right angles to the course of the dike.[1]

Tourmalin is also at times developed in the quartzite as well as the schists, but not in the same definite manner. It is not at all certain that dikes from the Alexandria bathylith are excluded from the category of rocks producing this contact effect. In many cases the dikes from the two bathyliths can by no possibility be distinguished from one another. In addition to these bands and bunches of abundant tourmalin, developed in this localized fashion, more scattered crystals of tourmalin, of the same evident origin, range much more widely through the rocks.

Smyth dissents from the view that the Picton granite was especially influential in the formation of these tourmalin zones, and in other contact phenomena. He points out that, in his belief, the tourmalin zones are most abundant at the extreme east end of Wellesley island, quite remote from the Picton granite, though with the Alexandria bathylith near at hand; also that the Alexandria bathylith is much nearer the Alexandria green schists than the Picton. He therefore regards the Alexandria bathylith as the most important granite of the region in producing contact effects. We are not sufficiently certain of the truth of the opposite view to urge it, and simply chronicle the matter as one on which we mildly disagree. It is not a matter of great importance in the interpretation of the geology of the region, on the general features of which we are in absolute agreement.

Contact amphibolites. Adams has recently shown conclusively that, in central Ontario, amphibolite occurs as a result of intense contact alteration of Grenville limestone by granite, limestones passing into rocks in which pyroxene, hornblende, feldspars and scapolite appear in increasing quantity up to final disappearance of calcite, and with final entire replacement of pyroxene by hornblende and scapolite by feldspar.[2] We have had the privilege of going over his territory with him, and fully agree in his conclusions. Perhaps the chief interest attaching to his work is the explanation thereby afforded of the abundance of inclusions of amphibolite in the Laurentian granite gneisses, where cutting the Grenville rocks,

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1 *op cit.* p. 190.
2 Adams, F. D. Jour. Geol. 17:7–18.

the scarcity of inclusions of other types, and the invariable utter absence of limestone inclusions, notwithstanding the abundance of limestone in the formation. Beyond doubt many of these inclusions represent limestone fragments altered in this fashion. Intense alteration, however, seems necessary, and that perhaps furnishes a reason why the comparatively small fragments caught up in the granite mass are so uniformly changed over, while at the contacts the change is much less obvious, or common. In our district here we have amphibolite inclusions everywhere in the granite gneisses, but no instances of the conversion of pure limestone into amphibolite along the contacts, similar to those in Ontario. There are, however, one or two instances of similar alteration on a small scale, in connection with narrow bands of limestone and small granite intrusions. The most clearly shown of these is right in the village of Theresa, at the road metal quarry near the lower bridge. The rock quarried here is a contact phase of the limestone cut through and through by granite dikes. The chief rock is green in color and consists of pyroxene, titanite, feldspars and calcite, the latter running as high as 50% of the whole in the portions of the rock most remote from the dikes. In contact with these, however, the rock is black, consists chiefly of hornblende and feldspars, though with a little remaining pyroxene and calcite, and has nearly completed its transformation into amphibolite. Very near at hand is the pure limestone band shown in plate 2, and there can be little question but that the green rock of the quarry is an altered phase of that, and no question at all but that the green rock is changed into amphibolite by the granite. On a small scale then it is a change identical with that described by Adams.

Contact rocks of the Antwerp bathylith. In so far at least as the portion of the Antwerp bathylith included within the mapped district is concerned, the contact action of this granite is but slight, and it would seem to have been quite deficient in mineralizing agents, though as effective in the production of mixed rocks as the other granites. The dikes and stocks of white granite run everywhere through the limestones without affecting them any, except in trifling amount in a few localities, nor does near approach to the margins of the bathylith produce any observable change in the Grenville rocks. In the case of dikes of granite pegmatite however, some contact action is the rule, coarsely micaceous rocks being the usual ones produced. Locally the mica becomes very coarse and in well formed crystals, so much so that at one locality north of Theresa an attempt was made to mine it commercially. The mica

is of light brown color, in the coarser varieties very light brown, resembling muscovite, though it seems undoubted phlogopite.[1] Scapolite is also an abundant mineral in these zones, a phlogopite-scapolite-calcite rock being the usual combination. This is not one of the customary types of Grenville contact rocks in the general region, though the common one here.

There are two other types of contact rocks which occur in small quantity within the area here, though common enough elsewhere, which call for brief attention. They occur in the district east of Redwood where Grenville rocks of all types are cut by small granite masses. One is a heavy, basic, black rock, weathering rapidly, and composed chiefly of green pyroxene and black hornblende, with a little graphite, considerable pyrite, and some 15% of calcite remaining. Heavy, pyroxenic rocks of this type occur throughout the Adirondack region at limestone contacts, though usually not so hornblendic as this rock.

The other rock consists of large, gray green pyroxenes set in a felt of tremolite needles, with rather abundant pyrite as the only accessory mineral. Such tremolite rocks occur not infrequently in the Grenville, the tremolite quite commonly altering to talc. The especial interest attaching to this particular exposure is that the tremolite rock is developed at the contact of granite against Grenville rusty gneiss, and seems quite certainly a result of the contact action of the one upon the other. So far as we recall, just that type of contact action has not heretofore been noted in the region.

Great Precambric erosion

The Grenville rocks are the only Precambric sediments in the region, and are of very early Precambric age. The remaining rocks of this age in the district are all igneous, and there is no evidence that any later Precambric sediments were ever deposited hereabouts, though it is possible that some such were deposited and subsequently worn away. The Precambric rocks of the present surface, both sedimentary and igneous, present characters which, so far as we know, are only given to rocks under conditions of high pressure, and at least moderately high temperature, conditions which in general prevail only at considerable depths below the surface. All the igneous rocks except the diabases give evidence that they solidified well beneath the surface, and the deformation of both these and the sediments is of deep-seated type. It is, however, not

[1] It is of the second order and with very small axial angle.

quite so prominently of this type as in the case of the corresponding rocks of the central and eastern Adirondacks. We are forced to argue that, when these rocks were deformed, a considerable thickness of other rock overlay them, which thickness was subsequently worn away. This surface wear goes on very slowly at best, and must have been continued through long ages, yet was completed before Potsdam deposition began. The time involved is many millions of years, in all probability a rock thickness of at least a mile or two was removed, and yet at the close the region was pared down to a surface of comparative smoothness. Much Grenville has thus disappeared, the tops of the igneous bathyliths are gone, together with whatever of younger rocks may have been present above them. The diabases were intruded toward the close of this long period, since plainly they solidified not far beneath the surface.

PALEOZOIC ROCKS[1]

The Paleozoic rocks of the district, for mapping purposes on maps of this scale, are separable into six quite distinct lithologic units, which in large part coincide with the subdivisions of these rocks made long ago by the early geologists of the State. These are, in order of age from below upwards, the Potsdam sandstone, Theresa dolomite, Pamelia limestone, and Lowville, Black River and Trenton limestones. Above the last named the Utica and Lorraine shales come in, but these nowhere reach the map limits, their northerly boundaries being found on the Watertown and Sacketts Harbor sheets, next south.

The basal member of this sedimentary series, the Potsdam sandstone, was deposited upon the worn surface of the Precambric rocks, and in order to properly describe the sandstone it is necessary to present in some detail the character of this surface.

Precambric surface underneath the Potsdam

That the surface on which the Potsdam sandstone was laid down was far from being an even one was clearly stated by Smyth, in his report on the district.[2]

That a similar irregular floor is present in many parts of Canada, of the upper lake region and of northern New York, has been shown by many observers. There is therefore nothing novel in the features to be described, but they are worthy of somewhat extended descrip-

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[1] By H. P. Cushing.
[2] N. Y. State Geol. 19th An. Rep't, p. r100–1.

Plate 6

The " granite knob " country. View taken from nearly 3 miles southeast of Theresa, looking southeast, showing one large and several small knobs of the Antwerp granite bathylith. H. P. Cushing, photo, 1907

Plate 7

A granite boss, Forsters landing, 3 miles east of south of Chippewa Bay, Alexandria quadrangle. H. P. Cushing, photo, 1908

tion since it is very exceptional to have the evidence as abundant and as clearly shown as it is here.

The evidence of surface irregularity is of threefold nature, (*a*) that given by exposures of direct contacts, (*b*) that given by the tracing of the lines of contact of the Potsdam and Precambric, even without exposures of the actual contact, and (*c*) that given by the topography of the present Precambric surfaces, since it can be shown that these surfaces are substantially those upon which the Potsdam was originally deposited; in other words that the Potsdam is just being pared away from the Precambric over part of the district, its numerous outliers testifying to its former presence over the whole and to the recency of its removal where now absent.

Where the Potsdam has been removed the Precambric surface disclosed is one of low ridges and valleys, with general northeast-southwest trend. The ridges are low and with hummocky surface, and the valleys are broad and shallow, and developed on the weak rocks (such as the limestones and weak schists) or on lines of structural weakness (as along lines of sheared and shattered granite). The extreme of relief does not much exceed 100 feet, and is generally less. The quartzites, resistant gneisses and some long and wide granite dikes constitute the ridges. In the relatively elevated country occupied by the igneous bathyliths the surface is of the knob and basin type [pl. 6 and 7]. The numerous granite dikes and small bosses which cut the limestone and are resistant to weathering, diversify the valley bottoms. Hence a large part of the area consists of slopes, and extensive flats do not appear.

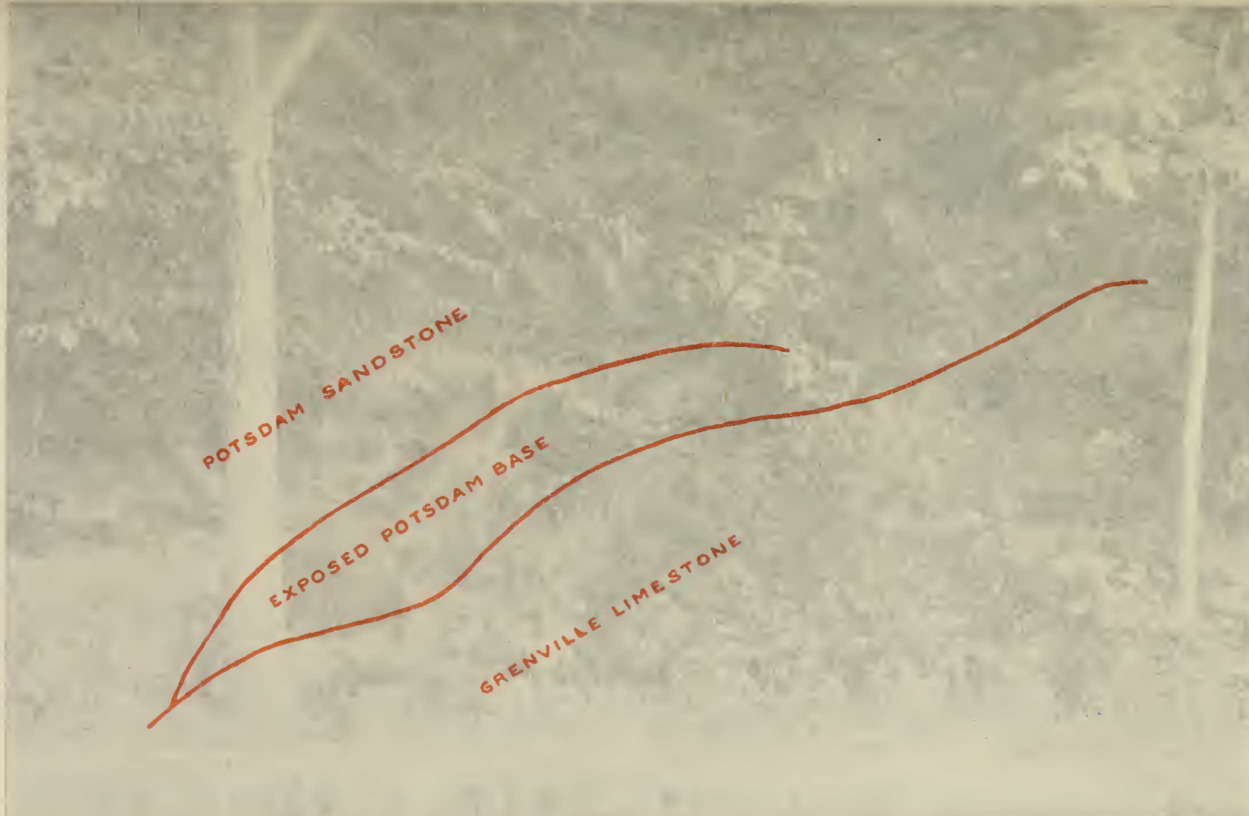
The surface underneath the Potsdam is precisely of this sort. The smaller Potsdam outliers are usually mere remnants remaining in places where the floor was lowest and the sandstone thickest. The larger outliers cover both high and low ground. The Potsdam resists wear, and hence usually presents cliff fronts at its margins, showing thicknesses of from 20 to more than 60 feet of sandstone, yet even with these thicknesses the summits of the outliers are often overtopped by neighboring granite knobs. The evidence of the occasional inliers of Precambric rocks in the Potsdam is even more obvious. The two small inliers east of Goose bay (Alexandria quadrangle) along the road from Alexandria Bay to Chippewa Bay, have their tops at the same level as that of the sandstone plain in which they lie, yet a 20 foot thickness of sandstone shows at the Potsdam margin, just to the northward. This line of evidence might be pursued at great length but since it is less conclusive than are the other lines the above will suffice.

The second line of evidence is that obtained in following and mapping the long Potsdam boundaries. A single example, that of the Potsdam margin along the west bank of Indian river in the southeast corner of the Alexandria sheet and for 1 mile southward on the Theresa sheet, will serve as well as a multitude of illustrations to indicate what the evidence is. The section is convenient since it has a horizontal base, the edge of the Indian river marsh. The Potsdam faces the river in a prominent bluff which, when it comes down to the marsh level, as it frequently does, forces the pedestrian to take to the swamp, so that the walk is not recommended as a pastime. But the unbroken cliff margin renders accurate mapping of the Potsdam base possible, and underneath it Precambric exposures are numerous. At the south end of this section, on the Theresa sheet, inspection of the map will show the Potsdam coming down to the river level in a point. Going northward it soon runs up the bank until the base is 40 feet above the river, with Grenville limestone outcrops showing beneath, then it returns to the river level and again rises, repeating the performance three times within a mile of distance. Soon after passing on to the Alexandria sheet the sandstone retreats prominently up the bank and back from the river, showing a 60 foot thickness of limestone underneath, then returns to marsh level, withdraws 30 feet up the bank, comes back again forming a point, retreats quickly for 60 feet up the bank and again returns to the river, all the while with limestone underneath, cut by occasional granite dikes, so that all these oscillations merely represent irregularities of the limestone surface. Northward from this last point of reaching the river, however, the limestone is cut out by granite gneiss, and this turns the Potsdam straight up the bank and out to the road, with a rise of more than 100 feet in the level of the Precambric surface. Equally striking are the oscillations in level of the same margin when followed southward on the Theresa sheet, and this margin is easy to follow, using the railroad as a base. There are many other excellent examples, since this sort of thing is the rule throughout the district. The mapping of the Potsdam base is thereby rendered laborious but nothing can be imagined more beautifully demonstrative of the character of the surface on which the Potsdam rests and its identity with that of the surface from which the Potsdam has been removed.

Lastly there is the evidence given by the actual contacts. There are quite a number of these, more than the writer has seen in the entire remaining border of the Adirondack region. Besides the actual contacts there are a host of others where but a few feet of

Plate 8

Contact of the Potsdam sandstone on Grenville quartzite by roadside 1 mile southeast of Redwood, looking west. The quartzite is somewhat contorted but its dips are not steep, from 20–30°. The upper view is from 15 feet distance, the lower with the camera only 4 feet away and showing only the lower layer of the Potsdam clearly. H. N. Eaton, photo, 1908



Contact of Potsdam [illegible] on Grenville [illegible] The Potsdam was deposited on a [illegible] leaving a portion of the [illegible] H. P. Cushing photo. [illegible]

Contact of Potsdam sandstone on Grenville limestone in Theresa village near the upper bridge. The Potsdam was deposited on a steepey sloping limestone hillside, and the limestone has now been somewhat eaten away leaving a portion of the actual under surface of the sandstone exposed. This is sparingly charged with pebbles. H. P. Cushing, photo, 1907

Upper view. Contact of Potsdam sandstone on Grenville limestone just north of lower bridge at Theresa, near the point at which plate 11 was taken. The Potsdam base rests against the side of a limestone hill, and the boy is seated on the limestone, with his hand resting on a portion of the Potsdam base from which the limestone has been removed.

Lower view. Nearer view of a portion of plate 9 showing the rotted limestone and the portion of the Potsdam base which projects out beyond it owing to removal of the limestone. H. N. Eaton, photo, 1908

space intervenes. This is due in part to the many miles of Postdam boundary in the region and in part to the scanty glacial deposit and hence abundant rock exposures. Many of the exposed contacts are on slopes, and on limestone, and it is these that are most unusual and interesting.

Plate 8 shows Mr Eaton's photographs of a contact on quartz schists, 1 mile southeast of Redwood on the Rossie road, a contact already described and figured by Smyth. The contact here is on the summit of a ridge of quartzite, hence is fairly horizontal where photographed, though the level drops away on each side at no great distance.

Two fine examples of contacts on slopes occur within the limits of the village of Theresa, along with others almost as good. One of these is by the roadside a short distance west of the upper bridge. A high Potsdam cliff borders the roadway for a few rods, with the base of the formation well below the road level. At the west end the base comes up to the road level, the cliff sets back some 20 feet, and the base rises sharply to from 12 to 15 feet above the roadway, exposing impure Grenville limestone underneath. The recess faces north, and is beset with shade of trees so that satisfactory photography is difficult, the view shown in plates 9, 10 being unsatisfactory. The surface of deposit has an angle of slope of 45° or more, and the soluble limestone has been somewhat eaten away from beneath the sandstone, so that several square yards of the actual basal surface are exposed. This is set with occasional quartz pebbles, but these are sparse, and except for them the rock is quite like that above. The sandstone is very massive and irregularly bedded, with a semblance of parallelism to the floor of deposit as is usual with the basal Potsdam hereabout.

The other contact mentioned is exposed on the north side of the river just above the lower bridge. The map shows a small Potsdam outlier there, whose narrow, southwest edge appears as a low cliff by the roadside [pl. 11]. The ground level falls toward the river and at the south end of the cliff the base of the sandstone is exposed, resting on Grenville limestone underneath. Plate 10 is a photograph of this contact. At the south the cliff bears sharply away from the road and by turning into the yard of the first house to the south a fine exposure of the south margin of the outlier is obtained, showing the Grenville limestone rapidly rising in altitude and carrying up the Potsdam base with it. The limestone surface falls not only to the west but also to the north. As in the previous case a part

of the sandstone base is exposed, owing to solution of the limestone beneath. A sketch of the relations here is given in figure 1, the

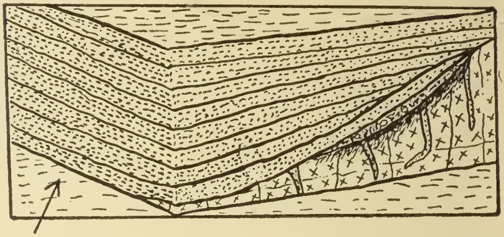


Fig. 1 Potsdam contact on Grenville limestone, just north of lower bridge at Theresa, showing the sloping Grenville hillside on which deposition took place, and the sand-filled cracks in the limestone.

arrow showing the camera position for plate 11. It is at this locality that the best examples of sand extending down into widened joint cracks in the Grenville limestone were seen. At the east end of the outlier the limestone is cut out by granite gneiss, whose summit is 20 feet above the top of the sandstone, hence terminating the outlier in that direction. Of course the full original thickness of the sandstone is not present in the outlier, but only the mere basal portion, and formerly the sandstone extended over the granite as well.

Another interesting contact occurs along the Potsdam front, 2½ miles northeast of Theresa. From a previous northeasterly trend the front here turns and for a mile and more runs northwest across the strike, crossing a prominent granite ridge and then dropping 70 feet in level into a limestone valley. Near the turn the contact sketched in figure 2 is shown. A low knob of ferruginous, quartz schist projects upward into the Potsdam to the amount of 20 feet.

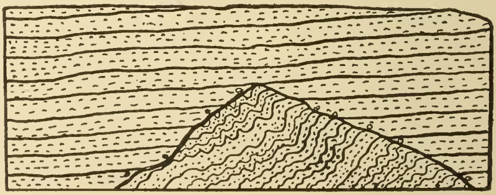


Fig. 2 Potsdam contact on Grenville quartz schist, 2½ miles northeast of Theresa. The much contorted and steeply dipping schists constitute a ridge over 20 feet high around which the Potsdam was deposited.

The Potsdam here is more evenly bedded than in the cases described at Theresa, the bedding abutting squarely against the sides of the knob. Its small size as compared with the long ridge slopes of the other contacts is thought to be the chief reason for this difference.

There is an occasional quartzite pebble along the contact, otherwise the sandstone is normal, and gives no sign of basal conditions.

Around to the left the slope of the knob steepens. There are occasional bands of coarsely crystalline, purer quartzite in the schists which are far more resistant to weathering. On this steep front one such layer projects as a cornice with the sand-filling beneath, as shown in figure 3. Photographic attempts here proved wholly unsatisfactory.

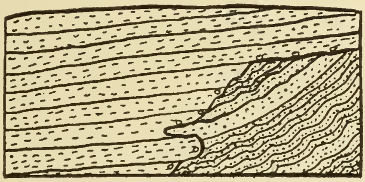


Fig. 3 A nearer view of a portion of the contact showing a local steep slope of the hill and projecting cornice of an extra resistant quartzite layer.

Besides the contacts on larger slopes, of which the preceding are instances, there are a number of minor examples of the sort, chiefly as filled hollows of the limestone surfaces. A sand-filled hollow of the sort appears at the top of the limestone quarry near the Theresa boat landing, and is shown in plate 2. In the section there shown the hollow is about 6 feet deep and with twice that width at the top. Another example may be seen at the quarry just south of the Theresa depot, though the overlying sandstone is gone except for the small residual patch resting in the hollow so that its original size can only be guessed at. A considerable number of other examples have been seen, some merely sand-filled, others containing rock fragments as well. In all cases the cement is calcareous and the rock weak and easily removed.

The above evidence of the character of the surface on which the Potsdam was deposited, is of precisely the sort so convincingly set forth by Wilson in his discussion of similar features in Ontario.[1] In New York these features are developed in a belt of considerable breadth across the strike, showing a great number of ridges and valleys, with patches of overlying Potsdam, and with the relief in every case owing to differential erosion on rocks of varying resistance, and in no case to subsequent folding. In this State exposed patches of residual materials resting on the old surface are more numerous than in Ontario, and these are in the depressions in all cases, showing that the depressions were in existence and served as receiving pockets for this material at the commencement of sandstone deposition. The evidence is abundant, clear and convincing that the Precambric surface underneath the sandstone is precisely like that where the sandstone is absent, and that the present topography of the Precambric areas is that resulting from recent stripping

[1] Wilson, A. W. G., Can. Inst. Trans. 7:146–55.

away of the sandstone; in other words that it is the reappearance at the surface of a topography of tremendous antiquity.

It further shows that this surface was little affected by the ice sheets of Pleistocene times, otherwise this identity of character could not have been so well retained.

Except for the local accumulation of a very scanty amount of residual material in small pockets in the depressions (and this almost exclusively quartzose) the Precambric surface, as it passes under the Paleozoics, is remarkably free from signs of surface decay, even the weak rocks being astonishingly fresh. In this respect also the conditions are like those noted in many places in Canada and the United States, as described by numerous observers.

The relief of the Precambric surface under the Potsdam is much the same in character here as elsewhere along the northern and eastern borders of the Adirondacks, but is apparently less in amount than it is further east, where there are differences in level of three or four hundred feet at least. The evidence there, however, is complicated by the presence of numerous large faults and is by no means so well shown as it is here. On the south border, in the Mohawk valley region, the surface was much smoother than here, exceedingly smooth in fact.

Potsdam sandstone

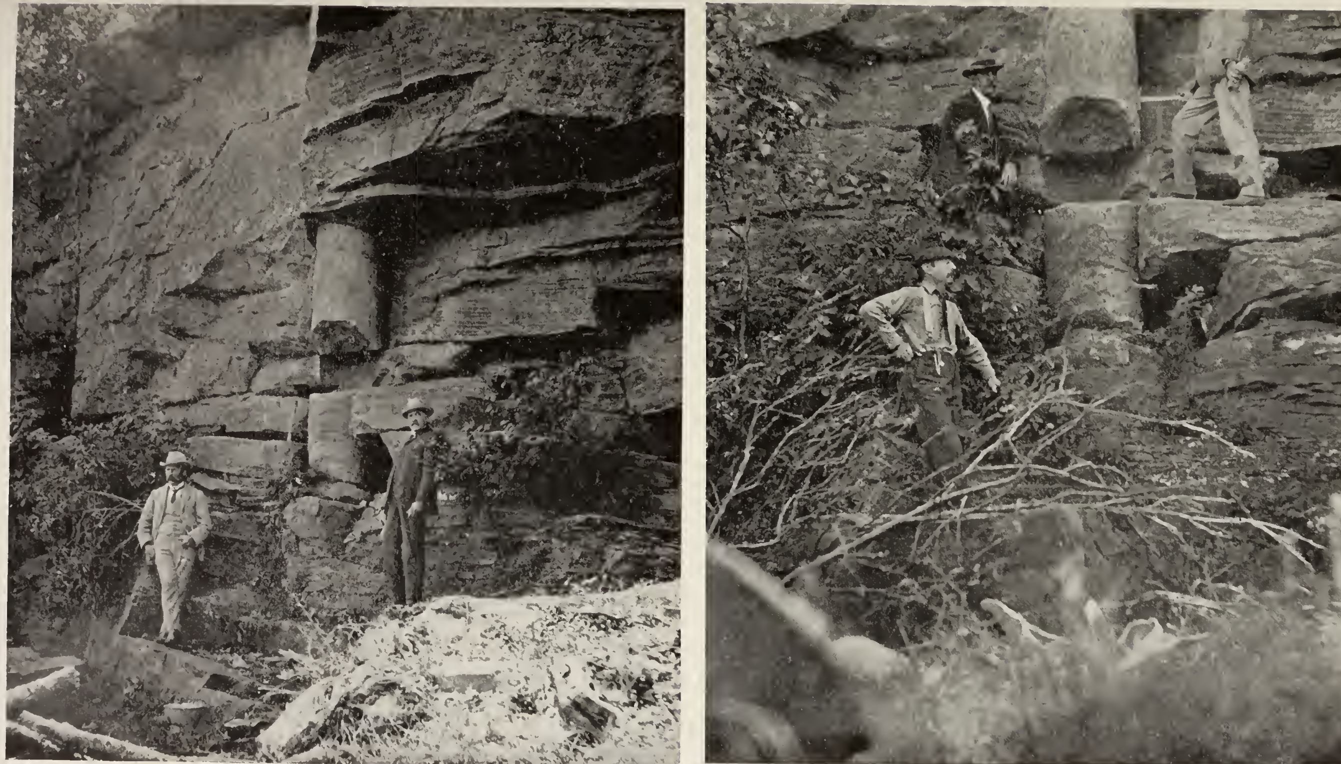
The first deposits laid down upon the worn Precambric surface consisted of medium grained, quite pure quartz sand, now firmly cemented to sandstone. On the Alexandria quadrangle the formation attains a maximum thickness of about 125 feet. This thickness diminishes both southward and westward, but shows a steady increase to the eastward of the area mapped. Within that the thickness of the sandstone is not greatly in excess of, or else does not quite equal, the variation of level shown by its floor, so that it is subject to continual variation from place to place, and thins to 20 feet or less over the old ridge summits. On the Theresa quadrangle, and on Wellesley island, it locally failed to overtop the highest of these, and the Theresa dolomite is found resting directly on the Precambric.

The bulk of the formation consists of a very pure quartz sand, quite thoroughly cemented with a silicious cement. The general color is light gray to buff, weathering white, but in the northern portion of the mapped area there is much red, or banded red and white rock in the lower half of the formation. The bulk of the formation is evenly bedded, and the greater part is thick bedded,

Potsdam sandstone in Theresa village just north of the lower bridge. Just to the right of the view its contact with the underlying Grenville limestone is exposed, the contact being on an irregular and sloping surface. The view illustrates the very irregularly bedded character of the Potsdam in such situations, which is certainly in part due to the irregularity of the floor on which it was laid down. H. P. Cushing, photo, 1906

Railroad cut in Potsdam sandstone 2 miles north of Theresa, looking east. Note its evenly bedded character as compared with plate 10; also the slight dislocation toward the right. H. P. Cushing, photo, 1907

Plate 13



Potsdam sandstone, Gildersleeve quarry, near Rideau, Ontario; red sandstone, somewhat banded with white. An excellent example of the "tree concretions" shows midway in each view. Right-hand photo by H. M. Ami; left-hand photo by Geological Survey of Canada.

with thinner bedded upper portions; where deposited on sloping surfaces the lower portion is often very massive, and quite irregularly bedded with a rude tendency to conform to the surface of deposit [pl. 11, 12]. Cross-bedding is present somewhat but in by no means prominent development. Ripple marks, however, abound. Much of the silicious cement has been deposited as secondary enlargement of the original quartz grains, the slides furnishing some beautiful examples of this.

Occasional long, cylindrical concretions (?) of a telegraph pole type appear in the sandstone, and are called "tree trunks" by the populace. As seen in cross section on rock surfaces they appear as circular portions of the rock, from 1 to 3 feet in diameter. On cliff sides they are long, vertical cylinders of sandstone. There is no perceptible difference in composition between them and the adjacent rock, but in every case the two are sharply separated by what may be for convenience styled a circular joint. No tendency to taper at the ends was noted, but the actual terminations were in no case seen. They certainly reach a length of 20 feet and may be considerably longer. Unless they represent a type of concretionary structure, we are wholly at a loss to account for them. If so they certainly are an unusual type both because of size and shape, and because of having the same composition as the inclosing rock. In plate 13 is shown an excellent example of one of them, in the Potsdam sandstone at Rideau, Ont., seen by us in 1908 under Dr Ami's guidance. This has been already described by the Canadian geologists, and is here introduced because, while corresponding precisely to the New York examples, it furnishes a much better illustration than any there seen.[1]

Only at the base and the summit does the sandstone vary from these general characters. Basal conglomerates are present in but scant amount, with small thickness and patchy distribution. The majority of contacts show only a few, scattered quartz or quartzite pebbles in the basal layer of the sandstone. There are, however, frequent patches of coarse, basal conglomerates, especially on the Theresa quadrangle. They seem in all cases to occupy local hollows in the limestone valley floors, and to occur only where the limestone contained thin quartzite bands, or granite dikes. The pebbles are all sizes up to that of the fist, and show little or no rounding in most cases, being usually very angular. They consist chiefly of quartzite and of white granite, though in some cases pebbles of red, quartzose sandstone also occur. The cement is

[1] Ells, R. W. Roy. Soc. Can. Trans., ser. 2, v. 9, § 4, p. 103.

calcareous in all cases. The angular form of the pebbles is due to the close jointing of the quartzite bands and granite dikes in the limestone, and the trifling amount of wear exhibited points to residual accumulation in the hollows, whereby they were protected from abrasion. The very small supply of such material, taken in conjunction with the small amount of decay shown by the underlying rocks, is a factor of much significance.

On the Alexandria quadrangle, both on the mainland and on Wellesley and Grindstone islands, a more extensive and bulky conglomerate occurs, which has already been described by Smyth [*see* pl. 14].[1] The most impressive display of this conglomerate known to us is that in the cliff along the St Lawrence in the extreme northeast corner of the Alexandria sheet where, rising sharply from the river level it reaches a hight of 20 feet above it. Here, as usual, the deposit has a calcareous cement which dissolves away, loosening the cobbles, and giving an exterior resemblance to a cobbly moraine, while the adjacent river bottom is solidly paved with the material which has already weathered out. The deposit is everywhere very coarse, a cobble deposit rather than a gravel. In the exposure here the cobbles run up to a foot in diameter, and average probably 3 inches. They are round to subangular and consist exclusively of Grenville quartzite. Smyth notes the presence of a few small pebbles from the tourmalin contact zones, but agrees in asserting the entire absence of granite and schist material, though several of the conglomerate outcrops rest on these rocks.

In addition many of the exposures show that the conglomerate is not strictly basal, but has pebbleless sandstone beneath, up to a thickness of at least 10 feet; and in all cases the abrupt transition from sand to coarse cobble at both upper and lower contacts is one of the most interesting features of the deposit. Its coarseness, its abruptness, its horizon, and the lack of variety in material of the cobbles render it an exceedingly difficult deposit to explain.

There occur, in a few localities on the Theresa quadrangle, small patches of a dark red, very thoroughly indurated and vitreous sandstone which thus differs from the general run of the sandstone of the district, though similar rock occurs in the formation elsewhere, as in the Clarkson quarry at Potsdam. As it occurs here it seems to be distinctly older than the general formation. All seen of it was absolutely basal, nowhere was the thickness as great as 1 foot and it is only visible at actual exposures of the Potsdam contact on the Precambric. But all the sand-filled cracks seen in

[1] *op. cit.* p. 199.

Potsdam conglomerate, Wellesley island, nearly opposite Point Vivian, and south of schoolhouse 21. H. L. Fairchild, photo, 1908

the Grenville limestone were filled with this type of sandstone, and it occurs frequently as pebbles in the otherwise basal conglomerates, being the only sort of sandstone occurring as pebbles in such situation. The thorough induration seems certainly to have taken place before the pebbles were formed. There seems no way to account for these conditions except to assume that there was an earlier deposit of sand in the district, likely in no great amount, and chiefly in the Grenville hollows, deposition ceased, thorough cementation followed and then erosion; in other words that there was a slight amount of deposition here in earlier Potsdam time, separated by an erosion unconformity from the bulk of the formation.

Occasional beds of black, and of mottled black and white sandstone appear in the upper part of the formation. The coloring matter is entirely in the cement, which is silicious, and is wholly discharged at a low red heat, hence likely organic.

In the uppermost 10 to 15 feet of the formation calcareous cement reappears, foreshadowing the change which gave rise to the overlying dolomite formation. In consequence of this the rock weathers easily to a weakly holding, brownish sand, usually mottled with spots of deeper brown. This portion is mostly thin bedded but terminates above in a very massive layer, 2 feet thick or more, which is comparatively resistant owing to its massiveness; and this heavy, brown mottled layer often full of small, rounded sand concretions, makes a convenient summit for the formation, owing to its relative prominence. The first layer of gray dolomite usually comes in directly above, and if not, no more than a foot or two of sandstone intervenes. The two formations grade into one another, so that any line of subdivision must be an arbitrary one. We have drawn it at the base of the first dolomite layer to appear, and this closely corresponds with the summit of this thick sandstone. There is, however, some reason for the belief that the base of the upper, calcareous sandstones should be made the division line.

With the exception of the long trails of an unknown animal, to which the name of Climactichnites has been given, some of which have been found in the sandstone 1 mile west of Theresa, no fossils have been found in the formation in this district except in these upper, calcareous beds.[1] In these a large linguloid shell (identified by Ulrich as Lingulepis acuminata) is quite common, and passes up into the lower beds of the Theresa formation.

[1] Woodworth, J. B. N. Y. State Pal. Rep't 1902. p. 959-66.

Theresa and Tribes Hill formations

These formations, as mapped, consist chiefly of rather thin bedded layers of blue gray, sandy magnesian limestone which are exceedingly tough and resistant rocks when fresh, but weather rapidly to an ocherous, rotten stone [pl. 15]. The basal portion, through a thickness of 15 feet, carries frequent beds of weak, calcareous sandstone in alternation with the limestone, the sandstone being identical in character and appearance with that forming the summit of the Potsdam. These form apparent "passage beds" between the sandstone and the limestone above. The overlying beds consist chiefly of magnesian limestone though occasional sand streaks continue throughout, and there is a varying and, in general, considerable amount of sand in most of the beds. While this tends to have a streaky distribution, it seldom wholly gives out. The sand is chiefly of quartz, certainly 90% of it consisting of that mineral, but grains of feldspar, mica, magnetite, pyrite, titanite and zircon are also present and all in quite fresh condition.

All the rock effervesces freely with acid, and the thin section shows this to be chiefly due to the presence of calcite cement, most prominent in the more sandy portions of the rock. A prevailing and highly characteristic feature of the rock is the appearance, on freshly broken surfaces, of lustrous calcite cleavages. These are due to the coarsely crystalline character of the calcite cement, the crystals ranging from ¼ inch to 1 inch in length, and inclosing a number of sand grains, so that they are veritable sand crystals. This lithologic peculiarity is a feature of the rock of this horizon across the entire northern border of the Adirondacks.

As mapped the general thickness of the formation over the district is from 60 to 70 feet, but the thickness is variable. The thickness steadily diminishes to the west and to the south in the same fashion as the Potsdam's. But there are also local variations in thickness which are to be ascribed to wear of its summit during an erosion interval which separated its completed deposition from the beginning accumulation of the succeeding formation. For instance it has a thickness of but 20 feet near the north end of Perch lake (Theresa sheet) though recovering its normal thickness of 60 feet both to the east and to the west and that the diminution in thickness is because of the wearing away of its upper beds with the production of a shallow valley is shown by the fact that the overlying formations thicken here by the same amount that the Theresa thins, and that the thicken

Tribes Hill limestone in creek wall 1 mile west of Lafargeville, looking west. The fairly massive beds, with their tendency to weather into thinner bedded form are well shown. Hight of section 15 feet. H. P. Cushing, photo, 1908

ing is due to the presence of basal layers which disappear to the east and west as the Theresa thickens.

The field work in the district was completed, and this report written under the impression that this comparatively thin formation was a unit and all of the same age. In its lower portion Lingulepis acuminata is abundant; above, specimens of a rather large, flat-coiled gastropod occur abundantly in places; occasional cystid plates are found, and unrecognizable traces of other forms. The horizon seemed the same as, and the beds identical with beds which directly overlie the Potsdam sandstone all across northern New York, a length of outcrop of 150 miles, and which have heretofore been called "passage beds" between the Potsdam and the Beekmantown, the Beekmantown being the formation which overlies the Potsdam for much of this distance. In the belief that no Beekmantown was present here, and yet that there was here a formation which required mapping separate from the Potsdam, the name Theresa was proposed for this magnesian limestone formation, it being well exposed in the township of that name.[1] Recent work by Ulrich, Ruedemann and myself in the Mohawk valley has, however, tended to throw much doubt upon the entire correctness of this position. We find that the formation in the Mohawk valley known as the Little Falls dolomite, and heretofore regarded as of Beekmantown age, is made up of two unconformable formations, the uppermost of which is of lower Beekmantown age, and is a quite fossiliferous limestone which we are proposing to separate and call the Tribes Hill formation; while the underlying dolomite formation is of Upper Cambric (Ozarkic) age. Now the Tribes Hill formation contains, as one of its fossils, a gastropod (named Pleurotomaria hunterensis by Cleland) which Ulrich regards as identical with the gastropod from the Theresa formation; it also contains numerous cystid plates, and these he also regards as identical with those from the Theresa. The Lingula, however, occurs in the Little Falls dolomite, instead of the Tribes Hill formation, and is in fact a characteristic Ozarkic fossil all around the Adirondack region. Ulrich's present view is therefore that the Theresa formation, as here mapped, is in part of Ozarkic, and in part of Tribes Hill (lower Beekmantown) age. If this be true there must be an undetected unconformity between the two portions. In the field the only lithologic difference noted between the upper and lower portions of the

[1] Geol. Soc. Am. Bul. 19:155-76.

formation was the absence above of the sandstone beds which are interstratified with the limestones in the lower division. Otherwise the formation constitutes an apparent lithologic unit and appears as such on the maps; and it seems better to leave it as such instead of attempting to subdivide it at this juncture. If, however, it does consist of these two separate formations the necessity for the name largely disappears, and it is rather a pity that it was ever suggested. It is likely, however, to prove useful as a name for the considerable thickness of alternating beds of sandstone and magnesian limestone which everywhere immediately overlie the Potsdam sandstone in northern New York, and which should be mapped separately.

There is then some reason to believe that there is present in this district a thickness of from 20 to 30 feet of limestone of lower Beekmantown age, quite like a similar thickness of rock at the summit of the Little Falls dolomite at Little Falls (where an unquestioned unconformity exists between the two), and holding the same fauna. This is to be separated from the Little Falls dolomite under the name of the Tribes Hill limestone, and the same separation needs to be made in this district. The Theresa formation is to be restricted to the alternations of sandstone and magnesian limestone which constitute the lower half of the formation as mapped.

Age of the Potsdam and Theresa formations. These two formations, with a maximum thickness in this district of from 125 to 150 feet only, represent the attenuated western edge of formations which, in the Champlain valley, have tenfold that thickness. Their distribution shows that they were deposited in a subsiding trough along the present St Lawrence valley line, and that their deposit commenced at the east and worked westward. Everywhere along this line we find a sandstone beneath, grading upward into an overlying dolomite, and everywhere the horizon is characterized by the presence of the fossil Lingulepis acuminata. Everywhere along this line too there seems to be a break between these formations and the next formation above. The two formations seem then to be indissolubly bound together, to rest unconformably on the Precambric, and to be separated by an unconformity from the overlying formation. Since the formations are thin in the immediate district, and are thinning to the west and south, it follows that we are here in the vicinity of the western edge of the subsiding trough. Just how far west its deposits extended can not be told. According to

Ells the Theresa formation outcrops on Howe island, and on the Canadian mainland to a point midway between Gananoque and Kingston.[1] In the district about Kingston, as seen by us in 1908 under Dr Ami's guidance, the Potsdam is certainly present, though no Theresa was seen. The Potsdam is in patchy distribution, in depressions of the old Precambric surface, and is still thinner than it is at Clayton. The Theresa may never have been deposited here, or it may have been thinly laid down and then eroded, prior to Pamelia deposition. But it certainly seems as if, here at Kingston, we are very near the westerly end of this old, St Lawrence, Upper Cambric trough.

On the basis of its fauna and position the Potsdam sandstone of northern New York was classified as of Upper Cambric age by Walcott, and in this he has been followed by practically all geologists. One can start on the formation at Lake Champlain and follow it without a break to Clayton, as a single continuous sandstone formation. Unquestionably its deposition commenced first at the east, and gradually extended westward; unquestionably the basal portion in the western sections is younger than the base in the east. But, so far as known to us, there is not a scrap of evidence to show that the deposition of sand had ceased, and that of dolomite begun on the east, before sand deposit had even commenced on the west. And even were this true, as is quite possible, there is certainly no evidence of such considerable age difference between the eastern and western ends of the formation, as to warrant their classification in two entirely different geologic periods, the one end Cambric, the other Ordovicic, as has been recently done by Professor Grabau, who classes the Potsdam here as of Beekmantown age.[2] That seems to us a stretching of facts to fit theory that is certainly not permissible. It is quite possibly true that the sandstone deposition slowly worked its way westward by progressive overlap, as the trough continued to subside; but the evidence seems to us to indicate clearly that the length of time consumed in the process is far less than Grabau would have us believe. We have now gathered evidence from many points in New York indicating that everywhere the Beekmantown formation is unconformable on what lies beneath. Detailed study of section after section has shown the presence of the unconformity in every case; and though the

[1] Roy. Soc. Can. Trans., ser. 2, v. 9, § 4, p. 97–108.
[2] Science, n. s. 29:356–58.

work is only begun we are strong in our belief that uplift of the whole region preceded the Beekmantown.

The type locality of the formation, at Potsdam, is precisely midway between Clayton and Lake Champlain. If one of these ends is of Potsdam, and the other of Beekmantown age, it is of interest to conjecture what the age may be at the type locality.

To the writer it has long seemed clear that the sandstone and the overlying dolomite must be classed in the same period, not only here on the west but everywhere in northern New York. By the overlying dolomite is meant not the true Beekmantown formation, but the dolomites which underlie this and which, the evidence indicates, underlie it everywhere unconformably. These dolomites have heretofore been classed with the Beekmantown and constitute Brainard and Seely's "Division A" of that formation in the Champlain valley, with the underlying "passage beds." But while the beds of this division grade downward into the Potsdam they are separated by an unconformity from the beds of "Division B" just above, as recently shown by Ulrich; because of which the writer has recently argued that, since this unconformity is everywhere present in New York, marking the emergence of the entire region, it forms the logical plane of division between the Ordovicic and the group beneath. If this contention be well founded, the Potsdam and Theresa formations, the Little Falls dolomite, and "Division A," fall into the upper Cambric group of present classifications. Ulrich has, however, recently proposed a different classification, involving the insertion of a new group of period rank between the Cambric and Ordovicic, for which he proposes the name "Ozarkic," and into which the Potsdam and Theresa formations would fall. For many reasons the writer is in accord with this suggested innovation.

Pamelia formation

In our district here the Theresa formation is everywhere overlaid by the limestone group here called the Pamelia formation. This is in some respects the most interesting formation in the section since it represents the thinned, shoreward edge of a formation which, while widepread elsewhere, has not heretofore been recognized in New York, and is in existence as a surface formation in the State only in this immediate area. Because of its wide separation from other areas where the formation appears, and because it represents only a local facies of the

mere upper part of the whole, the giving of a local name seems justified, and in Pamelia township the entire thickness is exposed. As has been shown there is plain evidence of an erosion interval between this and the Theresa, indicative of uplift to above sea level and of erosion on this land surface. As will be later shown this is an important and widespread break. The comparatively slight amount of erosion is indicative of low altitude for this land surface.

The renewed depression which initiated Pamelia deposition came in from the southwest instead of from the east, involving change in the direction of slope of the surface.

The formation consists essentially of limestone, though much of it is not pure limestone. It is conveniently separable into lower and upper divisions which differ in lithologic character. The lower division has always a sandy base, followed by alternations of black limestone, blue limestone and gray (somewhat magnesian) limestone, often with shaly partings between the beds. The upper division contains much whitish, earthy limestone, with interbedded dove limestone and gray magnesian limestone. The black limestone characterizes the lower, and the earthy and dove limestones the upper division.

In the western portion of the Theresa quadrangle the formation has a thickness of 150 feet or more. Traced eastward across the quadrangle it thins considerably, and on the eastern margin appears to have less than half this thickness though here the drift is so heavy, and exposures so poor, that no good measurements can be obtained. However, 60 feet seems a generous allowance for the thickness here, and it is the beds of the lower division which have disappeared.

Following the formation westward, across the Clayton quadrangle to its disappearance beneath the river, the belt of outcrop swerves somewhat to the north, and the formation thins somewhat in this direction also. If it could be followed due west across the quadrangle it would no doubt hold its thickness or even perhaps increase. It is the northward shift that causes the thinning. A thickness of at least 80 feet is maintained to the river however, and the formation passes across into Canada with this amount not materially reduced. The shore lines of this depositional basin then lay not far distant to the east and north of the district and the invasion of the sea must have come from the opposite direction.

In the immediate district the formation rests everywhere on the sandy dolomites of the Theresa. In the district about Kingston it

rests either on the Potsdam or on the Precambric. In the upper Black river valley it lies on the Precambric. All these formations are capable of furnishing sandy material and hence the sandstone base of the formation is but natural. The Theresa, however, is less capable in this respect than are the other formations, thus accounting for the fact that this sandy base is a less prominent feature of our area here than it is in the others.

Hereabout, the best section of this basal material seen is at the foot of the Pamelia inface, 2 miles east of Perch lake, Theresa sheet. The small creek there runs over a massive, bared layer of Theresa dolomite, above which a 14 inch layer of the same shows in the bank. Above this lie weak, greenish sands and sandy shales, with an exposed thickness of some 7½ feet, the basal layer somewhat pebbly and more massive than the remainder. The cement is calcareous and abundant. The rock is therefore weak and seldom exposed, yet in a sufficient number of places, and sufficiently well to show that it everywhere underlies the limestone throughout the district with a thickness of from 10 to 15 feet, much of which is shaly. It is a more calcareous, and vastly weaker rock than even the most calcareous beds of the Potsdam, and quite different from it lithologically; so unlike in fact that the two rocks can be readily distinguished from one another by lithologic character alone throughout the whole region. This becomes of importance in the region around Kingston, where in our opinion both sandstones are present but without the separating Theresa formation. The Pamelia basal sandstone rests, now on the Potsdam and now on the Precambric, is less shaly and attains greater thickness than on the New York side, and shows at times astonishingly coarse basal conglomerate. In its green color, weathering to a red mottling, in its abundant calcareous cement, and in its weakness, it corresponds exactly with the New York rock, while the silicious Potsdam beneath also corresponds with the Potsdam across the river in every minute lithologic detail, even in the "tree" concretions.

In the upper Black river valley both Potsdam and Theresa are absent and the Pamelia rests on the Precambric. At Martinsburg the wonderfully complete section shows a thickness of 19 feet for the basal sandy portion, weak green sandstone, blotched with red, abundant calcareous cement and with thin conglomerate at the base.

Where thickest, the limestones of the lower division show, above the basal sandstones, beds of gray, magnesian limestone with frequent shale partings; these are followed upward by black, fossiliferous limestones, holding a rather abundant marine fauna; then

succeed alternations of blue limestone and gray, magnesian limestone, with occasional white, earthy beds, and with thin recurrences of the blackish limestones with traces of the marine fauna; in the other beds the fossils are chiefly, or exclusively, ostracods. As the formation thins to the east and west the lower gray beds disappear, bringing the basal sands up under the black limestone; with further thinning this disappears in its turn, but at the same time the higher black layers seem to show increased thickness and prominence, so that where the lower division has been thinned to a few feet, as it has over much of the region, it is still characterized by black, fossiliferous limestone.

This lower division has a measured thickness of 70 feet in a nearly complete section by Perch lake. It is likely somewhat thicker to the west but probably does not exceed this more than 15 or 20 feet. A well near Stone Mills was drilled 125 feet in the formation without reaching the base, but drilling commenced in the upper division and how large a part of that is involved is not known, though likely 50 feet must be allotted to it.

The upper division consists of alternations of white earthy limestone, and of dove limestone, with occasional beds of gray, and of blue, hard, subgranular or subcrystalline limestone; there is also some yellow, earthy limestone, and a horizon where a reddish tinge is likely to prevail. The summit is chiefly of dove limestone. The earthy limestones hold numerous nodules of coarsely crystalline calcite, which attain quite large size in some of the upper layers, with diameters of from 3 to 5 inches. Celestite nodules also occur, but much less frequently. Much of the upper division is thin bedded, weathering into small, yellow stained slabs an inch or two in thickness; and the stone walls of this thin material which line the roadsides and separate the fields everywhere characterize the upper Pamelia country.

The surfaces of many of the layers are covered with shrinkage cracks, especially in the upper part of the division. Sand grains also appear in some of the white, earthy beds. Abundant Stylioliites occur at certain horizons in the upper dove limestones. The evidence of estuarine, or lagoon deposition, with evaporating waters, occasional exposure of broad mud flats, and from time to time replenishment of the water from the sea outside, freshening it and bringing in traces of the outer marine fauna to mingle with the ostracod fauna of the lagoon, is very plain and conclusive; prevalence of somewhat arid climate is also suggested. The rock is very like, and the climatic and depositional conditions very simi-

lar to those which prevailed during the formation of the Siluric waterlimes of central New York.

The thickest measured section of the upper division, 1 mile southwest of Depauville, Clayton sheet, gave a thickness of 82 feet. The contact with the overlying Lowville was shown, and the base of the section can not have been greatly above the base of the upper division. Near the river west from Clayton a similar thickness was found, though the upper part of the section was considerably interrupted. In all probability the thickness does not vary greatly from this over the entire map limits, with the exception of the eastern margin of the Theresa quadrangle. The thickness of the two divisions together then indicates a maximum of about 150 feet for the formation hereabout.

The fauna of the formation consists chiefly of ostracods, which are found at all horizons, and Ulrich remarks on the absence in the formation of certain large sized species of Leperditia and Isochilina which occur in the Lowville above. The marine fauna of the lower division includes gastropods, cephalopods, lamellibranchs, trilobites, corals and sponges. The most abundant and characteristic form is the coral Tetradium syringoporoides, which abounds in certain layers of the black limestone. The most common trilobite is a species of Bathyurus which is very like the common Bathyurus extans of the Lowville, but which Ulrich distinguishes as a different and unnamed species, which is a common Stones River form. Among the gastropods he identifies Lophospira perangulata, another Lophospira, and a Helicotoma. The fauna as a whole is quite similar to that of the Lowville, though the differences are characteristic.

Since the formation is a new one to the State the publication of a few detailed sections is advisable. The best continuous section of the lower division is found in the bed of a small creek which tumbles down the steep bluff face east of Perch lake (Theresa sheet), cutting the 400 foot contour where the figure 400 appears on the map.

6′	White, earthy limestone in thin beds, often shaly looking
3′ 6″	Brittle, tough, blue to blue black limestone, thick bedded
1′ ½″	Gray, subgranular, magnesian limestone, weathering white
1′ 5″	Massive bed of blue, subcrystalline limestone
1′ 3″	Massive bed of gray, magnesian limestone
5″	Blue, subcrystalline limestone
1′ 8″	Gray, magnesian limestone, two layers
1′	Concealed
3′	Finely laminated gray to blue gray, magnesian limestone, fine-line weathering on edges
10′	Concealed
10′ 3″	Black to blue black, fossiliferous limestone, upper 3 feet thin bedded, remainder fairly massive

Plate 16

Exposure 1¼ miles east of Perch lake, of limestones of the lower division of the Pamelia formation; about 6 feet of black, fossiliferous limestone above and twice that thickness of gray, magnesian limestones beneath. H. P. Cushing, photo, 1907

8′	Gray magnesian limestone, weathering whitish, fairly massive below, upper 2 to 3 feet thin bedded and earthy
1′ 6″	Curdled looking intergrowth of blue limestone and gray, magnesian limestone, the former weathering most rapidly with production of fantastic weathered surface
19′	Alternating, gray, earthy, impure magnesian limestones, and thin, shaly looking partings, limestone weathering at times to a greenish tinge, at other times whitish
2′	Greenish to olive, calcareous shale
2′	Greenish, calcareous sandstone, coarse, well rounded sand grains set in calcite paste
72′ ½″	

The lower 4 feet of the section belong with the basal, sandy portion of the formation, without any question, so that the actual base is nearly reached. Above is a thickness of 28 feet of impure, magnesian limestone before reaching the base of the fossiliferous black limestone, the most characteristic member of the lower division. Plate 16 is a photograph of beds of this horizon exposed in the creek bed just north of the road 1¼ miles east of Perch lake. In the section here 14 feet only of gray magnesian beds are found underneath the black limestone, as against the 28 feet of the Perch lake section. A mile further east these have disappeared letting the black limestone down on the basal sand beds, or rather bringing them up to it.

Judging from other sections the concealed 10 feet of the section is occupied by weak, earthy, thin bedded, whitish limestone, and the section would be capped by a very massive, blue, subcrystalline limestone which forms a strong shelf everywhere through the district.

The best sections of the upper division are all on the Clayton quadrangle. One measured up the bed of the small creek which tumbles down the bluff into the Chaumont river a mile southwest of Depauville is as follows:

1′ 8″	Brittle, light gray, subcrystalline limestone
16′ 1″	Thin bedded, brittle limestone, mostly dove, but with beds of grayer limestone
1′	Massive layer of dove limestone
10′ 8″	Irregularly bedded, gray to white, earthy limestone, mostly thick bedded; midway is somewhat sandy
5′	Thick bedded, uneven, gray limestone
3′	Thin bedded dove limestone in 3″ to 6″ layers
4′ 2″	Gray white, earthy, irregular limestone, both thick and thin beds
5′ 4″	Dark and light gray, brittle, subcrystalline limestone
1′ 8″	Gray white, impure, earthy limestone
1′ 8″	Brittle, blue gray, subgranular limestone
5′ 10″	Impure, earthy, white limestone, irregularly bedded
1′	Hard, blue gray, subcrystalline limestone
57′ 1″	

The section terminates downward 20 feet above the river level. Above, after a 10 foot gap, come 15 feet of thick and thin bedded, dove limestone, often mud cracked, and then the Lowville base, giving an 80 foot thickness to the section. It is not certain whether its base overlaps the summit of the previous section of the lower division or not, though it is thought not. But the uppermost 6 feet of that section belong to the upper division and the thickness is nearly the same as that of the impure, earthy limestone at the base of this section. Even granting that amount of overlap, the two sections taken together give a *certain* thickness of 150 feet to the formation and this may need to be increased by from 10 to 20 feet.

Another most excellent section is that given in a quarry up the river bluff 4 miles west of Clayton [pl. 17]. A slightly generalized statement of it will serve the purpose here.

1′ 8″	Thin bedded, dove limestone
5′ 6″	Gray white, impure earthy limestone, mostly thin bedded, some thick and irregular beds
7′ 5″	Rather massive limestone beds averaging 20″ in thickness, gray in color, in part earthy, in part subcrystalline
2′ 9″	Dove limestone, three beds, the lower thick, the two upper thin
3′	Hard, gray, subcrystalline limestone, two thick beds with a thin shaly parting between
1′ 5″	Dove limestone, two beds
1′ 8″	Hard, gray limestone, upper inch is shale
1′ 8″	A hard, dove limestone layer
1′	Gray white, earthy limestone, thin bedded
2′ 9″	Brittle, gray, subcrystalline limestone
1′ 8″	Massive, dove limestone bed
11″	Thin bedded, whitish, earthy limestone
1′	Gray, subcrystalline limestone, slight pinkish tinge
7′ 1″	Gray, earthy limestone in thick beds with shaly partings; a thin dove layer near the top; reddish tinge at times
9′ 6″	Blackish limestone, upper bed very massive
49′	

The black limestone at the base of the section seemed to the writer to smack strongly of the lower division, though the marine fauna was but feebly developed, and Ulrich expressed doubts in the matter. Certainly beds of the type are not usually found in the upper division. A short distance back from the river another quarry shows a thickness of 15 feet of the succeeding beds, the entire thickness being of dove limestone, both thick and thin beds, with sparing fossils. Further back, by the roadside is a shallow quarry exposing 4 feet of still higher beds, two massive dove layers with similar but thinner beds between, the thick beds holding Phytopsis. Such beds elsewhere mark the extreme summit of the Pamelia. Were the upper part of the section complete there would be shown here a thickness of more than 80 feet belonging to the formation.

Plate 17

Quarry in the upper Pamelia formation, by the river 4 miles west of Clayton; alternating beds of dove limestone, and whitish, earthy limestone. The upper view is a somewhat more distant one showing a greater thickness of the upper beds. Photo (upper) by H. M. Ami and (lower) by E. O. Ulrich, 1908

Plate 18

Upper view. Dove colored limestone beds of extreme upper portion of Pamelia formation in railroad cut just south of Sanford Corners. Theresa quadrangle, looking east.

Lower view. Contact of Pamelia and Lowville formations at the south end of the railroad cut. E. O. Ulrich, photo, 1908

Both these sections are imperfect in their showing of the beds of the extreme summit. The most excellent section shown in the railway cuts just south of Sanford Corners (southeastern part of Theresa quadrangle) supplies this deficiency [pl. 18].

1′ 4″	Two 8″ layers of blue gray, crystalline limestone, abundant lamellibranch casts full of crystalline calcite; dove limestone mud balls
1′	Mud cracked, argillaceous, somewhat granular, bluish limestone, weathering yellowish
1′	Thin bedded, blue, granular limestone, conglomeratic, quite shaly below, very fossiliferous, chiefly bryozoa; base of Lowville
11″	Dove gray, fine, impure limestone, weathering light
3′ 2″	Laminated, mud cracked, gray dove, argillaceous limestone, thin bedded, ripple-marked, worm-burrowed
1′ 9″	A 6″ layer below and an upper 15″ bed; fine dove limestone with calcite spots, gastropods and cephalopods
1′ 10″	Gray, granular limestone, crystalline specks and spots; shaly below, more massive above
5′ 6″	Finely granular, blue dove limestone, shaly below, more solid above; blocky weathering; calcite seams and spots; sparse Phytopsis in upper part
4′ 6″	Mottled, blue dove limestone, thin bedded above and below; much crystalline calcite replacing poorly preserved fossils
8″	Blue black, finely granular, dove limestone; calcite spots
1′ 10″	Blue gray, calcareous, sandy shales, weathering yellowish
7″	Dark blue, finely crystalline limestone; conglomeratic
8″	Blue gray, calcareous shales, weathering yellowish; sand grains
8″	Blue dove limestone; base weathering sandy looking
9″	Sandy, argillaceous, shaly limestone, weathering yellowish
9″	Blue dove, mottled limestone
3′ 1″	Gray blue, dove limestone, somewhat muddy, shaly fracture
7″	Blue dove limestone, small limestone pebbles
1′ 9″	Solid layer of blue dove limestone, rudely laminated with organic streaks
1′ 10″	Laminated, argillaceous, fine grained, mottled, blue dove limestone; two seams
1′ 4″	Fine, flinty, dove limestone; slightly conglomeratic at base
1′ 10″	Fine, flinty, dove limestone, with a shaly streak of 3″; lower portion with Phytopsis
4′	Rather compact, fine dove limestone; a little Phytopsis in the upper 3″
1′ 2″	Blue dove, thin and irregular bedded limestone
2′ 6″	Measures concealed
5″	Blue dove, mottled, laminated limestone, small ostracods
45′ 5″	Of which the lower 41′ 8″ belongs to the Pamelia

The 1 foot layer, third from the top of the section, is divisible into an upper 3 inch portion, full of fossils, making an irregular contact with the remainder, which lacks fossils, and in Ulrich's judgment, with which we coincide, the line between the two formations is properly drawn at that slight break. These upper dove limestone layers, over 40 feet thick in this section, have puzzled us much and have been difficult to classify. They are above the white, earthy beds which are the most characteristic lithologic feature of the upper Pamelia, and while they are precisely like the dove limestones

which are intercalated with these, they are also very like the Lowville, with which we at first classified them. Their shift from the one to the other considerably diminishes the supposed thickness of the Lowville of the district and correspondingly increases the Pamelia.

In this cut, the first of three such along the railway south of Sanford Corners, the rock dip is to the south, carrying the Pamelia summit below the track level before reaching the second cut. The dip then reverses, becoming north, and bringing up the Pamelia again in the third cut. At the north end of this cut the basal, bryozoan, conglomerate layer of the Lowville has increased in thickness to 38 inches, as against a 3 inch thickness in the section just given, and immediately beneath it is a layer of exceedingly fine grained dove limestone mud, which is the exact counterpart of the material composing the conglomerate pebbles [pl. 31, lower figure]. This layer was wholly lacking also in the previous section. At the south end of the cut the Lowville shows 6½ feet thickness of basal layers which did not appear in the section in the north cut, and there is also a thickness of full 6 feet of the pebble-furnishing, dove limestone at the Pamelia summit, which is also lacking in that section. The evidence of unconformity between the two formations is clear, and found as Ulrich had predicted that it would be. The fact that both formations thicken together is, however, somewhat unusual, and suggests that some of the warping shown occurred in the uplift following Pamelia deposition, its summit being protected from wear in a shallow trough, in which also the first beginnings of Lowville deposition took place.

The section here in the south cut is given on page 84 under the account of the Lowville formation.

The section just described gives an excellent idea of the depositional conditions which prevailed during the closing stages of Pamelia deposition. The fine limestone muds, much sun cracked, worm-burrowed, even ripple-marked; the injection of sand grains and the occurrence of the occasional limestone conglomerates, together with the abundance of ostracods and the general absence of marine forms; all these point unquestionably to intermittent deposition in a shallow lagoon, with drying mud flats produced from time to time, and with only occasional admission of sea water. Though the uppermost break, here chosen as marking the base of the Lowville, seems much the most considerable of all, the presence of more than one conglomerate horizon, of more than one horizon of sand grains, indicates several minor breaks in the summit of the

formation, and much complicates the successful working out of the section.

Extent of the Pamelia formation. In a preliminary paper published some months ago, based on the field work up to the close of 1907, the writer attempted to predict the extent of the Pamelia formation in New York and adjacent Ontario, in so far as the published literature warranted. The result of the field work of 1908 necessitates some modification of the statements there made, all of which prove to have been too moderate.[1]

The study of the formation on the Clayton sheet, and the work about Kingston, show that the formation does not thin as rapidly in those directions as had been supposed. About Kingston the formation has much prominence and considerable thickness, much of the upper division, and the basal sandstones being well represented. The upper dove limestones of the New York section are here capped by thin bedded, earthy, shaly layers, weathering yellow, above which the Lowville comes in, with its basal conglomerate. The division plane between the two formations is therefore much easier of recognition than on the New York side.

Up the Black river valley we measured sections at Lowville and on Roaring creek, near Martinsburg, the latter a wonderfully fine, continuous section from the Precambric up into the Trenton. We were at the time ignorant of the fact that Prof. W. J. Miller was engaged in the areal mapping of the Port Leyden sheet, on which this section occurs. That being the case its detailed exposition is left for him.[2] Suffice it to state that it shows a thickness of 72 feet, 6 inches of Pamelia, overlaid by 54 feet, 7 inches of Lowville; and that, of the Pamelia, the lower 19 feet is of sandy beds, followed by 8 feet of blackish limestone with abundant marine fossils, the remainder showing alternating beds with the characters of the upper division though the upper dove beds are lacking. Miller reports that the formation is traceable to the south line of the Port Leyden sheet, but does not appear beyond. This is, however, well toward the upper end of the Black river valley, and gives the formation in New York a measured length of outcrop of 70 miles, from southeast to northwest. The Kingston occurrence adds 15 miles more to this distance, and it is quite probable that the formation may run west for some miles across the Ontarian peninsula.

Our work was done, and a preliminary paper published, while in ignorance of the existence of a paper by Dr Ells upon the adjacent Canadian district. This paper, as the quotation which follows will

[1] Geol. Soc. Am. Bul. 19:165-71.
[2] N. Y. State Mus. Bul. 135, p. 22, 23.

show, distinctly recognizes the chief physical oscillation of the region.

It would, therefore, appear that some marked but well defined change of level occurred in the area south of the Kingston-Brockville Archaean axis at the close of the Potsdam, which was also materially reduced in thickness. This is in marked contrast to the conditions which prevailed north of that axis throughout the Ottawa basin; and it may be supposed that, at a certain stage in the deposition of the sandstone formation, the surface was raised above the level of the sea, and so remained till the beginning of Black River time throughout the whole extent of Lake Ontario.[1]

Age of the Pamelia formation. Our section here shows the Pamelia formation to lie between the Theresa and Lowville formations, separated from each by an unconformity, the lower of which is much more important than the upper. In the Champlain valley two great formations, the Beekmantown and the Chazy, with a combined thickness of 2000 feet, occupy this same interval, yet the Pamelia formation is unlike either. On the basis of its position and fauna, Ulrich correlates it with the upper part of the Stones River formation, a formation of Chazy age, but laid down in a separate basin from the Chazy, so that faunally and lithologically the two are quite distinct. The Stones River basin lay to the west and southwest of the Chazy trough, and was much larger. The barrier between the two in New York comprised the Mohawk valley region, much of the Adirondack district, and at least the westerly portion of the St Lawrence trough.[2]

Curiously too, although much sedimentation occurred in the Champlain trough during Beekmantown-Chazy time, and only Pamelia deposit in our district here, yet this is practically un-

[1] Roy. Soc. Can. Trans. ser. 2, v. 9, § iv, p. 106.

It is to be noted that Black River is here used in a general sense as including the whole body of limestone.

[2] Since the above was written another paper by Professor Grabau has appeared which presents more definitely his interpretation of the rock succession and age in this district [Jour. Geol. 17:211-26]. The fundamental difference between us seems to be that he regards the break between the Theresa and Pamelia formations as representing the somewhat expanded westward continuation of the break in the Champlain valley between the Beekmantown and Chazy, and recognizes no break there between the Cambric and Beekmantown. We regard it as representing most of Beekmantown and all of lower and middle Chazy time and think that, to the east in the St Lawrence valley, it splits into two breaks with a wedge of later Beekmantown inserted between. He thinks there is no Cambric here, and that the Potsdam and Theresa are of Beekmantown age; and he recognizes no break between the Cambric and Ordovicic. We find evidence of a considerable series of oscillations of level in the general region, while he argues, if we correctly understand him, for a slow, progressive subsidence of the region during Potsdam and Beekmantown time.

represented in the Champlain area, Ulrich correlating the dove, reef limestone, only a few feet in thickness, which forms the basal member of the upper Chazy there, with the Pamelia horizon. In the much more complete sections about Chambersburg, Pa., a 200 foot thickness of limestone with an upper Chazy fauna, separates the Pamelia horizon from the Lowville. Subsidence apparently ceased in the Champlain basin during the time of Pamelia depression and deposit in this district, and as this ceased here, upper Chazy depression was renewed there, the unconformity between the Pamelia and Lowville representing this upper Chazy interval. Knowledge of this led Ulrich to predict the unconformity and induced the search for it. Otherwise it might easily have escaped our notice.

Mohawkian series[1]

The Mohawkian series comprises the Black River and Trenton groups. The Black River group is composed of the Lowville beds including the Leray limestone, and the Watertown limestone. In giving to the Black River group this larger scope, we return to the original conception of several of the geologists of the First Geological Survey of New York, i. e. Hall, Vanuxem and Mather, with the exception that the Black River then also included the Chazy limestone. Emmons, however, to whose district the Black River region belonged, did not use the term "Black River." He distinguished the "Birdseye limestone" and the "Isle La Motte marble" employing the latter term for a bed locally the main object of the quarrying industry, and known as the "Seven foot tier." Hall, in the first volume of the *Palaeontology of New York*, restricted the term Black River to this "Seven foot tier" and through his influence and the description of a very striking cephalopod fauna from the bed, the term "Black River" was quite generally accepted for the "Seven foot tier." Since, however, mainly through the investigations of Dr Ulrich, the fact has become apparent that beds which in the Mohawk valley and the Lake Champlain region have been referred to the Black River limestone, are both older and younger than the Black River as restricted by Hall, but fall within the limits of the original conception of Black River, it has become advisable to revive this original usage of the term to avoid confusion. The "Seven foot tier" or Black River limestone of Hall has then to be renamed and the term "Watertown" is here used for this formation [*see* p. 84].

[1] By R. Ruedemann.

Lowville limestone. The Lowville limestone which is the "Birdseye limestone" of the old Geological Survey reports has its maximum development in New York in the region of the lower Black river, or in the southern portion of the area here mapped. It reaches there about 60 feet in thickness. It consists typically of thick and thin bedded, fine grained dove limestone which shows a characteristic ashen gray weathering and contains either numerous more or less vertical worm tubes denoted as Phytopsis and filled with calcite (producing the "birdseyes" in sections) or shows in profusion the horizontally spreading tabulate coral Tetradium cellulosum and related species. Between these typical Lowville beds there are intercalated others of subcrystalline dark to black limestone, or of oolitic or also of shaly whitish weathering limestone. These intercalations usually contain a larger fauna than the dove limestone and carry lamellibranchs, gastropods and cephalopods, as well as ostracods and trilobites.

The basal bed is conglomeratic and of very variable thickness; it is overlain by several feet of strata that contain quartz grains or grit bands and are more or less shaly, the shaly limestone gradually becoming more massive upward and assuming the characters of the typical rock. These more or less sandy beds comprise about 4 feet.

The uppermost portion of the Lowville beds which has been mentioned by the earlier authors as the "cherty beds" has been found by Professor Cushing and the writer to be quite distinct from the typical Lowville beds and separated from them by an unconformity. It has for that reason been here distinguished as a subdivision under the name Leray limestone and will be described separately [*see* below].

It appears that in this region the Lowville beds beneath the Leray member can be conveniently divided into an upper and lower division of nearly equal thickness, the upper division alone containing the abundant Tetradium cellulosum and larger Phytopsis, as well as the typical massive dove limestone strata, while in the lower division more dark or black subscrystalline limestones containing only smaller forms of Tetradium and Phytopsis and more thin bedded dove limestones abound.

In this lower division also two or more horizons of Stromatocerium can be observed, which give the beds a very irregular concretionary appearance. These horizons are well seen in the railroad cut just south of Sanford Center, also where the road crosses

the southern branch of Horse creek on the Clayton quadrangle and best along the Black river just east of the boundary of the map. Such beds are seen in the lower third of the exposure on plate 19; other bunchy surfaced layers also appear, with the depressions filled in with shaly material, which seem clearly due to rill action on tide flats.

While the sand grains which are found in greater or smaller number floating in the basal limestones indicate, if we may follow recent investigations, the conditions of quiet embayments, in which sands washed in from the land, drifted out into the bay and gradually sank to the bottom, becoming imbedded in the limestone mud, the following beds indicate that this sea became gradually deepened. The lower division still exhibits in the shaly beds the sun cracks and ripple-marks and numerous mud balls characteristic of mud flats while the upper beds in their more uniform, massive character contain the criteria of deposition farther off the coast line. It follows thence that the Lowville sea was an advancing sea in the area here mapped. From the development of the Lowville in the Mohawk valley and north of the Adirondacks, it can be inferred that this transgression took place from the southwest. In the Mohawk valley the distribution of the Lowville is very erratic, as fully discussed by Cushing in a former paper [Geology of the Northern Adirondack Region], it being entirely absent in some localities while in others it is connected by so called passage beds with the underlying Beekmantown. This erratic distribution is then clearly due to the irregularity of the surface over which the sea advanced, the Mohawk valley intersecting the deeply indented coast line of the Adirondack peninsula in Lowville time. In the Champlain basin at the base of the Black River group an outcrop of typical Lowville rock occurs in the Crown Point section. The bed referred to consists of 5 feet of dove limestone with Phytopsis tubes but otherwise apparently unfossiliferous. However, 12 feet above this dove limestone the writer found a large colony of Tetradium cellulosum together with Orthoceras recticameratum, another typical Lowville fossil, thereby clearly demonstrating the presence of the Lowville fauna in the Champlain basin.

Four species of fossils have to be considered as highly characteristic of the Lowville formation in the area here mapped, viz:

Tetradium cellulosum (*Hall*)
Orthoceras multicameratum (*Emmons*) *Hall*
O. recticameratum *Hall*
Bathyurus extans (*Hall*)

These species are not known to occur above or below the Lowville limestone, and are common enough to occur in every exposure of the formation.

Tetradium cellulosum forms large colonies, attaining sometimes a diameter of several feet (specimens of this size collected by the writer along Black river) and consisting of frequently dividing branches that radiate horizontally and obliquely upward from a common center. Its most characteristic aspect, however, is seen on sections where the squarish cells with their fission septa produce a neat lattice pattern. Different, hitherto undescribed species with looser arrangement of the polyparies or cells, occur in lower horizons.

Both Orthoceras multicameratum and O. recticameratum are easily recognized by the close arrangement of their septa and the latter form possesses in the angular course of the septa a character not shown by other species.

Bathyurus extans apparently occurs throughout the formation but is most frequent in several bands. It is, as Dr Ulrich informs us, preceded by closely related and very similar prenuncial forms in the Pamelia formation.

On account of the but slight difference in the compactness of the rocks between the Lowville and Pamelia formations, the former is not set off by an escarpment from the other, but both form one continuous plateau. In some districts the lower Lowville contains easily worked layers, furnishing subcubical blocks and the composition of the fences of such blocks is a quite characteristic aspect for this horizon.

Since the formation received its name from Lowville and a section of this type locality has not yet been furnished, we insert here the section, obtained at this place in the quarry at the railroad bridge over Mill creek, where in the creek bank the uppermost part of the Pamelia (about 12 feet) is shown and a continuous section into the Leray limestone can be obtained. On account of the nearness of Lowville to the area here mapped, the Lowville section is to be considered as typical also for this area. For comparison we add the section measured in the Sanford cut which contains about three fourths of the formation. Another fine section was observed in the bank of the Black river above Watertown, opposite the filter plant, just outside the map limits, and a section of about 56 feet from the 7 foot tier downward is exposed in the high river bank opposite the Ontario Paper mill, 2 miles east of Brownville.

Unfortunately no good sections were found in the northwestern portion of the area, permitting a comparison with that of Lowville as to thickness and arrangement of horizons.

Section at railroad bridge at Lowville (type section)

Lowville section	
6′	Cherty beds. Dark blue, finely granular limestone, dirty white weathering. Columnaria horizon at base
1′ 6″	Bed full of horizontal worm tubes. Chert horizon at base
5′ 9″	Transitional bed from Leray to typical Lowville. In aspect like cherty beds with a few cherts, but contains also Tetradium cellulosum, besides Leperditia fabulites, Rafinesquina minnesotensis, and other brachiopods and bryozoans
	Base of Leray
3′	Dove limestone, massive. Phytopsis tubulosum common near top; a few Tetradium cells
3′ 1″	Compact dark dove limestone, full of fossils (Tetradium, gastropods, lamellibranchs) and of crystalline calcite
4′ 9″	Thin bedded, dove limestone, full of Tetradiums (form with narrow, round tubes)
5″	Dark, fine grained impure limestone with argillaceous streaks, containing a small Monticulipora
2′ 4″	Lighter, massive bed of dove limestone with few Tetradiums. Lowest 8 inches black, with thin seams of flint
4″-7″	Stratum of granular, light gray limestone full of lamellibranchs and gastropods, their shells filled with calcite
1′ 3″	Black, massive, crystalline limestone, full of Tetradium
3′ 4″	Black to dark gray thin bedded dove limestone, containing a few Phytopsis
4″	Same rock as above, but full of a narrow form of Phytopsis
4″	Black, dove limestone stratum full of crystalline calcite
1′ 7″	Dark gray, granular limestone with many calcite crystals. Bottom of quarry
4′	Dark gray, thin bedded, dove limestone, weathering shaly
4′	Harder, argillaceous limestone
3′ 10″	Shaly dove limestone, varies much, very shaly in middle, full of sand grains, contains a few lamellibranchs
1′	Hard, oolitic blue limestone, full of quartz grains and pebbles
6″-10″	Shaly bed with seams of quartz grains or grit bands
0 - 3′+	Dark bluish gray limestone, full of pebbles, shale below. Very variable in thickness. Unconformity. Base of Lowville
1′ 10″	Gray and pinkish granular limestone, dove in parts
4″	Thin bedded, shaly limestone, sand grains near top
1′ 10″	Dove, dark mottled, fine grained limestone, typical upper Pamelia
1′ 7″	Dove limestone with argillaceous reticulation, light pink in parts, weathering shaly
9″	Bluish black flinty dove limestone
10″	Gray, granular limestone with calcite and quartz grains, in parts conglomeratic, a few fossils. (Rafinesquina incrassata)
1′ 5″	Light dove limestone, somewhat argillaceous, coarsely laminated. Phytopsis on top
2′	Grayish, bluish, blocky, subgranular limestone
1′	Compact bed of harder, light bluish gray limestone
1′+	Dove, light gray limestone with crystalline specks

Sanford cut section

27′ 2″	Lowville
1′ 4″	Blue gray, oolitic limestone, full of lamellibranchs and with Tetradium cellulosum
6′	Massive Tetradium beds, dove limestone full of crystalline calcite
5′	Thin bedded, blocky dove limestone; second zone of Bathyurus extans
4′	Irregular, thin bedded, blocky, dove limestone, more massive above, culminating in a heavy, irregularly surfaced Stromatocerium layer; holds B. extans below
22″-14″	Thin bedded, fossiliferous, dove limestone, with Camarotoechia plena, fitting to uneven surface beneath
16″-24″	Heavy, massive dove limestone, Tetradium and other fossils, masses of Stromatocerium at surface, giving bunchy character
4′ 6″	Speckly dove limestone with shaly seams; bryozoa, Tetradium syringoporoides (Ulrich, ms) and other fossils
3′ 2″	Heavy, massive bed of gray, crystalline limestone, full of fossil fragments at base, bryozoa and gastropods above; conglomeratic, many quartz grains, base of Lowville
1′ 6″	Shaly, dove, mud limestone, three beds; very fine, even grained, cherty looking

Leray and Watertown limestones. Emmons had already pointed out that the Seven foot tier was closely connected by its lithologic character with the underlying formation, and the writer had found, while in preceding years collecting the cephalopods of the formation, that the characteristic cephalopods of the "Black River" limestone for which the Watertown region is renowned among paleontologists, viz, Gonioceras anceps, Hormoceras tenuifilum, Lituites undatus and also the "Black River" coral Columnaria ?halli (=C. alveolata auct.) appear already below the Seven foot tier,[1] while at the same time the characteristic fossils of the Lowville cited above, especially also the omnipresent Tetradium cellulosum, disappeared. Since this faunistic extension downward of the "Black River" is coupled with a greater lithologic similarity of the uppermost 20 feet of the Lowville, as formerly conceived, with the "Black River" than with the typical Lowville, and this upper portion of the Lowville is characterized by seams of chert nodules which make good horizon markers, we decided to draw the Lowville-Black River line where Tetradium cellulosum abruptly disappears and the chert layers begin. In mapping the "Black River" on this basis, it was found that, on the whole, the cherty limestones also exhibit the characteristic blocky weathering of the Watertown bed,

[1] While these cephalopods first appear in greater number in the cherty beds just below the 7 foot tier, a few stragglers either identical or only prenuncial mutations of them, have already been noticed in much earlier horizons of the Lowville. Thus Hormoceras tenuifilum and a large colony of Columnaria ? halli were noted 11 feet below the cherty beds in a Tetradium bed in the section opposite the filter plant at Watertown.

and are a unity with them also in that, as a rule, they together form a distinct escarpment above the Lowville plateau. In some cases, however, the lowest 2 or 3 feet of the chert beds have remained clinging in very irregular patches to the underlying Lowville, thus forming the serpentine shaped outliers seen in the southern portion of the map.

The authors, under the necessity of drawing a definite boundary line between the "Black River" and Lowville limestones, which would meet the requirements of being lithologically and faunistically so well marked that it could be mapped with sufficient ease and precision, decided on uniting the cherty beds with the Seven foot tier, the two forming a physiographic and economical unit, as demonstrated by their being quarried together at Chaumont and other places. Dr Ulrich's investigations had shown him a more complete section in Kentucky from which it became apparent that the cherty beds are intimately connected there with the rest of the Lowville and that the unconformity observed in the Watertown region between the cherty beds and the other Lowville represents the hiatus which is filled in Kentucky and elsewhere by beds of transitional character, while on the other hand the cherty beds were found to be also separated by an unconformity from the overlying beds. Since, moreover, the "Seven foot tier" or Hall's "Black River limestone" is of but local importance, while the Lowville, including the cherty beds, is a most persistent unit over a very large area, it has been finally deemed preferable by the authors to disregard the local conditions of the Watertown region, and to retain the "cherty beds" limestone as a subdivision of the Lowville limestone, under the term "Leray[1] limestone," on account of the typical exposures in the town of Leray.

The following diagram indicates the relations of the beds as now understood by us:

Black River group	Watertown limestone	
	Lowville formation	Leray limestone member
		Lowville limestone s. str.

Since a very irregular surface is observable beween the uppermost tier of cherty beds, about 6 feet thick, and the underlying beds [*see* section of Klock's quarry, *postea* p. 90], and this bed contains the cephalopods more frequently than the other cherty beds, Dr

[1] Owing to an error of the printer this word was made to read Leroy on page 72 of Museum Bulletin 138.

Ulrich is inclined to unite it with the Seven foot tier or Watertown limestone. We adopt here this view, leaving the final decision as to the exact boundaries to a future close study of the faunas involved, but consider the difficulty of an easy recognition of this boundary — located within a lithologic unit — in the field as another practical reason for mapping and discussing here the Leray and Watertown limestones together.

Finally, it was found in studying last summer, in company with Dr Ami, Professor Cushing and Dr Ulrich, the section at Klock's quarry at Watertown [*see* below p. 90], that there is properly referred to the Watertown also a bed 1½–2 feet thick, of black limestone, that still overlies the Seven foot tier.

With these upward and downward extensions of the formation, the limestone will be about 15 feet thick in its type region while the Leray limestone is about 13 feet thick, consisting of dark gray to black, heavily bedded, dove limestone, with layers of black chert nodules. The nodules are more or less scattered through the chert beds, forming here and there strings in the section and a distinct horizon over the whole mapped area near the base of the beds. Since large rock exposures of the surface of the Leray limestone are frequent in the region, one has often opportunity to observe large quantities of these cherts, half weathered out, on the rocks, presenting a flat, cakelike form. Some of the chert beds present, when weathered, a peculiarly fucoidal surface through intricate intermixing of the limestone with earthy films, and others are distinctly cross-striated.

The contrast between the massive chert beds and the thinner bedded underlying Lowville strata is well shown in plate 20. In natural exposures or where the quarry face is weathered, the Watertown and Leray formations are readily distinguished from the lower Lowville beds by their breaking up into small cubic blocks the size of a fist. The beginning of this breaking up, which is apparently due to a reticulate system of mud seams, is seen in plate 20 and farther progressed in plate 21. Here the rock is so weathered that it can be brought down with the pick and is of convenient size for road metal. It is also well shown on plate 19, where the hat lies just above the boundary line. This picture exhibits especially well the contrast between the evenly and thinner bedded typical Lowville limestone and the thick bedded blocky weathering Leray and Watertown beds.

In plate 22 will be found an excellent illustration of the unconformity between the Lowville and Leray limestones. The lower of

Leray limestone resting on upper Lowville in quarry at Threemile Bay station, Clayton sheet, looking north. Note the reef layer of Stromatocerium midway in the Lowville. H. L. Fairchild, photo, 1908

Upper portion of the Lowville limestone with overlying lower Leray limestone, full of chert, showing its thick bedded character as compared with the underlying Lowville. Quarry 2 miles northeast of Watertown and near the south margin of the Theresa sheet. Shows also, on the right, a joint widened by solution, with thick turf-filling above. H. P. Cushing, photo, 1907

the two massive beds of Leray limestone which appear in the upper view is absent in most sections, as in plate 20, where the basal Leray bed is the equivalent of the upper bed of plate 22. In addition most of the Lowville shown in plate 22 is absent in other sections, the top Lowville bed in plate 20 being the equivalent of the basal bed of plate 22.

The Watertown limestone is a solid bank of dark bluish gray to black limestone, with rather indistinct bedding planes, very hard when fresh, showing numerous small calcite crystals (crinoid joints) and a fine reticulation from mud seams and many worm tubes. The mud seams or the earthy intergrowth causes the rock to break up most typically in small blocks.

When fresh the Leray and Watertown limestones, especially the Seven foot tier, furnish very large blocks. They are for this reason still extensively quarried at Chaumont where at present the immense blocks required for harbor improvements at Oswego and other cities along the Great Lakes are obtained.

The fact that the 1½–2 feet of black, knotty, impure limestone which overlie the Seven foot tier are separated by a very irregular contact from the overlying horizontally bedded Trenton, indicates that also this bed should be properly included in the Watertown formation.

The Seven foot tier and the just mentioned top bed of the Watertown formation owe their deep black color to the great amount of organic matter in the rock. This saturation with organic matter shows itself also in the presence of petroleum in the rock. In the large quarries at Chaumont endoceratites and other cephalopods have been found whose chambers were partly filled with petroleum and the writer was in a cellar in the hotel in Black River village above Watertown that is cut in the Watertown limestone and in which the petroleum is constantly oozing out of the cellar walls in such quantities that the floor is constantly covered with the oil and gallons of it are taken out for cleaning and oiling purposes. The top layer of the formation is especially strongly bituminous, and gives off a strong odor when struck with the hammer.

The upper beds of the Black River group of the neighborhood of Watertown have become world famous among paleontologists by the fine preservation and size of their cephalopods, some of which, notably G o n i o c e r a s a n c e p s, have not been found elsewhere. It is essentially a cephalopod facies. The straight conchs of H o r m o c e r a s t e n u i f i l u m with their large pearly siphuncles, are especially common on the many ice-polished rock surfaces of the

region and on the rock shelves bordering the river. They are well known to the populace as "fish bones" which they indeed much resemble when broken through the middle. Also two species of large Endoceras, distinguished by Hall as Endoceras longissimum and E. multitubulatum are frequently seen to attain several feet in length and half a foot in diameter. Gonioceras anceps, readily recognized by its lyre-shaped septa, is rarer and Lituites undatus, another of the characteristic cephalopods of the formation is also less frequently observed. There is also a fairly large fauna of brachiopods and gastropods present, which, however, has been generally lost sight of since the fossils are hard of extraction in the massive rock and inconspicuous in comparison with the large cephalopods. This smaller fauna has not yet been described.

Physiographically the Leray and Watertown limestones form by far the most striking feature of the region. Their massiveness and hardness as compared with both the underlying typical Lowville limestone and the overlying shaly Trenton beds cause them to form a distinct plateau or terrace, rising with a frequently vertical escarpment from the Lowville exposure. This escarpment, however, does not present the straight face of the Helderberg cuesta but is deeply indented or composed of many parallel ridges separated by about equally wide valleys, and stretching in fingerlike groups for miles upon the Lowville plain. These fingers are especially well seen on the map northeast of Limerick, and west of Perch river. They rise abruptly from the Lowville plain while the intervales rise more gradually to the level of the Watertown limestone plateau. The direction and form of these fingerlike erosion ridges and their relation to the prevalent direction of jointing in each special case suggest that they originated from ice plucking between especially deep and wide joints.

The Watertown limestone plateau is in comparison to the small thickness of the formation abnormally wide and the Watertown belt correspondingly broad on the geological map. This is due to the fact that the Trenton rocks are little compact and were easily swept off the massive Seven foot tier by the ice. The latter forms thus the surface rock over a very large area and is in many places swept clear of soil. This fact and the many deep joints make it a very poor underground for agricultural purposes, and the plateau is therefore frequently wooded, especially so the jagged and deeply jointed boundary region along the Lowville belt. Even small brooks have frequently formed deep solution and erosion ravines in this forma-

Leray limestone overlying Lowville, 2½ miles northwest of Sanford Corners. The view illustrates the characteristic weathering of the Leray. Dr Ruedemann is at work on the upper surface of the Lowville. H. P. Cushing, photo, 1907

Upper view. Leray limestone overlying Lowville in quarry 1½ miles south of Sanford Corners, looking south. A thickness of 9 feet of massive limestone of Leray character is shown, of which the upper half is equivalent to the basal cherty bed shown in plate 20, while the lower bed does not appear in that section. The Lowville shown beneath consists of beds which are higher than any in that section.

Lower view. Upper Lowville in quarry very near to that in the upper view, and showing the beds just beneath these there shown. The uppermost beds here shown are also absent in most sections, the Leray resting on some of the lower beds. H. M. Ami, photo, 1908

tion. One of the best examples of such a gorge is that of the Perch river at Limerick. Many brooks disappear entirely under the Watertown formation, forming long underground courses and caves. Several such courses are know in Watertown, where, however, they have been filled by the damming up of the river. Others are known below Watertown and at Black River village.

Phenomena entirely peculiar to this formation in the region are the inliers at the Natural bridge and Limerick. A glance at the Watertown-Leray belt on the Clayton sheet north and east of Chaumont bay reveals the fact that in several places the typical Lowville beds appear from beneath the Watertown-Leray limestones. These inliers consist of elongate strips of Lowville limestone exposed along brooks and surrounded on all sides by the Watertown-Leray limestones. The conditions which have produced this peculiar and rare form of inlier are the following: The coincidence of the dip of the beds and of the course of the brook and the greater resistance of the underlying Lowville limestone to solution. The brook as a rule reaches the inlier by a fall, and finally leaves it again by very gradually passing again upon the overlying rock.

A very characteristic example of such an inlier is seen along Threemile creek and a very large one at the head of Guffin bay. The most interesting of all is that below the village of Limerick on Perch river. It begins with the fall shown on plate 23 and ends above the Natural bridge. At the latter place the river passes underground through a ridge of Watertown-Leray rocks crossing the valley. Below the bridge the river reappears for a short distance [pl. 38] and disappears again, its course being thence traceable as a depression between the cliffs of Watertown-Leray rocks on both sides. The depression shows in the different tilting of the huge blocks of the Seven foot tier that it is the result of a gradual sinking down of the whole mass; and this indicates that the river, which has its underground course on the top of the typical Lowville beds, is dissolving the Watertown-Leray beds along its course from the base upward. There is little doubt that also the inlier above the Natural bridge, which can not have been produced by normal corrasion, is the result of solution of the Watertown-Leray beds, and that finally also between the Natural bridge and the lake the typical Lowville beds will be exposed and the river flow again overground, as it already does just below the bridge.

One of the best exposures of the Watertown-Leray beds is that at Klock's quarry, at the end of Huntington street at Watertown. This section which is here inserted, begins close to the base of the

Leray limestone and reaches to the base of the Trenton. The contact with the typical Lowville beds is shown on the opposite side of the river and on Diamond island. Plate 24 shows a part of the quarry.

Section at Klock's quarry, Watertown

1½'-2'	Black, knotty, impure, dark limestone with Strophomena filitexta, Leperditia fabulites, Orthis pervetus, Isotelus platycephalus, Orthis tricenaria, Illaenus americanus, etc.
7'	7 foot tier. Heavy black limestone, with Gonioceras anceps, Hormoceras tenuifilum
6'	Dark gray to black, heavily bedded, cross-striated limestone with a few cherts, containing also Endoceras, Gonioceras. Resting on an irregular surface; base of Watertown limestone
2'-2½"	Irregularly bedded, dark to black, dove colored, fine grained limestone, characterized by weathered, fucoid, earthy markings
5'+	Fine grained dark gray limestone, with cherty layer on top. Cherty beds. Bottom not shown

These chert beds are in this neighborhood underlain by 4–5 feet of fine grained dark gray beds with Tetradium cellulosum, which also weather blocky like the Watertown limestone. Below this are found the dove colored, thinner bedded, typical Tetradium beds.

A series of good sections of the Watertown-Leray limestone are exposed in the large quarries about Chaumont. Since, however, the Seven foot tier forms here the top of the section and an unknown thickness of the same is always eroded, the thicknesses obtained are always a minimum. In the large quarries at the head of Chaumont bay the combined beds measure 18 feet; in the big quarries along Chaumont river 19 feet of these limestones are found, below which 22 feet of typical Lowville beds are exposed to the river edge.

Trenton limestone. The last of the Lower Siluric stages occurring in the area of the map is the Trenton limestone. It appears first in outliers near the mouth of Black river, then occupies the southern portions of the peninsulas jutting out into Lake Ontario and finally on the Cape Vincent sheet forms a continuous belt. In contrast to the underlying formations and notably its direct predecessor, the Watertown limestone, which forms a remarkably level plateau with a distinct escarpment at the northern boundary, the Trenton appears in well rounded hills, its boundaries approach subcircular curves, in contrast to the many fingered and deeply indented Watertown exposures. This is due to the fact that the Trenton is a much thicker and at the same time a much less resistant formation, consisting almost entirely of thin bedded limestones with shaly intercalations. It is therefore also much more covered by drift and as a rule exposed only along the shore line or

Plate 23

Falls of Perch river at Limerick, Clayton quadrangle; cliffs of Leray limestone overlying Lowville. E. O. Ulrich, photo, 1908

Upper view. Watertown limestone near river at Watertown, showing seven foot tier and the upper portion of the cherty bed beneath.

Lower view. Trenton limestone in creek bank near Threemile Bay, Clayton quadrangle. A closer and more detailed view of part of the section shown in plate 25. E. O. Ulrich, photo, 1908

on the *stoss-seite* of the hills. But since the thin limestone slabs over the Trenton belt have been incorporated in great quantities into the drift, whence they have found their way into the stone fences, these stone fences composed of thin Trenton slabs are almost the most characteristic feature of the Trenton formation in the district and they are remarkably closely bound to the present distribution of the Trenton.

The contact between the Black River and Trenton groups is but rarely seen, but where found, it indicates an unconformity, either by the irregularity of the contact line, as at the Klock quarry at Watertown, or by the presence of a basal conglomerate bed in the Trenton as at Threemile Bay.

The best continuous exposure, or in fact the only good one within the boundaries of the mapped area, is that found along a brook at the western outskirts of the village of Threemile Bay [pl. 24, 25]. This section is given below. Another fairly complete section can be obtained from Klock's quarry to the top of Pinnacle hill at Watertown and a third, which however lacks the base, at the west end of Carleton island in the St Lawrence river.

Section of lower Trenton limestone at Threemile Bay
(generalized)

16′-17′	Fine grained thin bedded limestone with shaly intercalations
3′	Thin bedded limestone layers with shaly intercalations, rich in lamellibranchs, gastropods and cephalopods
10′	Fine grained black limestone with shaly partings, in part barren, in part full of fossils on shaly partitions, mostly large conical or hemispheric bryozoans (Prasopora simulatrix) in horizon about 2 feet from base
3′ 6″	Black, fine grained limestone full of worm tubes, no other fossils
5′ 6″	Gray, crystalline, thin bedded limestone with many crinoid joints on top (2 feet) and fine grained dark thin bedded limestone below, with shaly intercalations. The limestone beds full of brachiopods (Dalmanella, Rafinesquina) and bryozoans
6′	Dark gray to black compact limestone, in strata 1 foot thick with thin shaly partings. Very fossiliferous. Dalmanella testudinaria, Plectambonites sericeus, Calymmene, bryozoans (Pachydictya acuta) and crinoid joints
5″	Conglomerate bed with crystalline matrix and crinoid joints
	Base of Trenton
....	Black River beds

It follows from this and the other sections that the Trenton begins with a thin conglomeratic bed, on which rest about 6 feet of dark gray to black compact limestone, in beds about 1 foot thick, with thin shaly partings. The latter are very fossiliferous, containing most profusely Dalmanella testudinaria, Plectambonites sericeus, Pachydictya acuta and crinoid joints.

This black basal limestone of the Trenton contrasts strongly with the equally thick underlying Seven foot tier in being a most inconspicuous element in the physiography of the region. In fact its presence is hardly suspected over the greater part of the area, since it is nearly always hidden at the base of the rounded Trenton hills. Only where the formations are planed to one level, as about Rosière, is it observed to outcrop as a recognizable belt.

The remainder of the Trenton, as far as the area of the map is concerned, consists then of about 50-60 feet of thin slabby limestones, with shaly intercalations. The limestones are partly gray and crystalline with many crinoid joints and partly fine grained, dark gray to black. The latter limestone swells sometimes into thicker beds (1 foot thick and more) of black limestone which is either quite barren of fossils save worm tubes, or as on Carleton island, almost entirely composed of the shells of Plectambonites sericeus.

Plate 25 shows the general aspect of the thin bedded limestones in the creek bed at Threemile Bay and plate 24 which gives a closer view of the rocks in the same locality, illustrates the regular alternations of limestones and shales in the formation.

The greater middle and upper part of the Trenton is found in the region south of the map, on the other side of Black River bay.

The fauna of the Trenton has the general aspect of that of the formation in other parts of the State. Its details have not yet been studied.

SUMMARY OF PALEOZOIC OSCILLATIONS OF LEVEL[1]

It has been shown that the Potsdam and Theresa formations were deposited in the west end of a sagging basin or trough which occupied the general line of the present St Lawrence valley; that the deposition began at the east and worked westward, involving our region here only in its later stage; and that the depressed trough was a westward extension from a similar subsiding trough along the Champlain valley line. There the Potsdam is very thick, is followed by beds similar to those here called Theresa, and these are overlaid by nearly 400 feet of dolomites which have been heretofore classed with the Beekmantown formation, as Division A of that formation. No such beds as these last appear in our district here, though the Potsdam and Theresa may be equivalent to them in time. In the Champlain valley also appear four other divisions of the Beekmantown, with an aggregate thickness in the neighborhood of 1400 feet

[1] By H. P. Cushing.

Thin bedded limestones of lower Trenton age in creek bed at Threemile Bay, Clayton quadrangle, looking northwesterly, upstream. H. P. Cushing, photo, 1908

Ulrich has recently made the important discovery of an unconformity between these beds and Division A, and we coincide in believing that this division is properly to be classed with the beds below rather than with the Beekmantown. The Beekmantown that is thinly present in the district here reported upon is not of the Champlain type, but of the Mohawk valley type, lithologically and faunally quite like the beds at Little Falls and thence eastward through the Mohawk valley, which have heretofore been called the "fucoidal beds," and which we are proposing to call the Tribes Hill formation. This Beekmantown did not come into this northern district from the east but from the south, and so far as we know did not extend on eastward. But in passing to the eastward, beyond the limits of the region here mapped, Beekmantown beds begin to appear above the Theresa, and in our belief are unconformable, though this has not yet been demonstrated. Also in our belief this Beekmantown is not representative of the lower portion of the formation but of the upper portion, and we must go yet farther east to find the lower beds coming in; while the thin edge of Tribes Hill Beekmantown in our district here is lowest Beekmantown. Following a condition of uplift Beekmantown submergence seems to have commenced fairly simultaneously on the east, west and south sides of the Adirondack region. Submergence on the west was quickly followed by emergence due to a general eastward tilting of the region, so that at Little Falls and about Theresa only a slight thickness of the very lowest Beekmantown was laid down, the Tribes Hill formation. This formation steadily thickens to the eastward, along the Mohawk valley, though apparently representing nothing but the lowermost Beekmantown. The chief area of Beekmantown sedimentation in New York was the Champlain valley trough and its prolongation southward. Along with the steady subsidence in that trough seems to have gone a subsidence of the St Lawrence trough which, like the previous Potsdam subsidence, seems to have commenced at the east and worked westward; so that, in that trough, the lowest Beekmantown is absent, and steadily higher beds are at the base going west. The extreme westward reach of this Beekmantown depression of the St Lawrence trough seems never to have reached the Theresa district, where the only Beekmantown represented is the thin base of the Tribes Hill formation of the Mohawk Beekmantown type. Until the Beekmantown on the north side of the Adirondacks has received more thorough study, this view of Beekmantown conditions in the St Lawrence trough can not be regarded as based on sufficient evidence, though evidence on the other three sides of the Adirondack region

in respect to these conditions seems now quite well substantiated. Our immediate district in late Cambric (Ozarkic) time sloped to the east and received the thin deposit of Potsdam and Theresa beds laid down in the western end of the St Lawrence trough. Uplift followed throughout New York, producing unconformity between these beds and those of the Beekmantown which follow. Beekmantown subsidence seems to have commenced simultaneously on the east, west and south sides of the Adirondacks, with a tilting of the surface in our district here, so that its slope was to the southwest, instead of to the east. This was quickly followed by tilting of the whole region to the east, stopping Beekmantown deposit on the west and south sides of the Adirondacks and confining it to the eastern trough. From this trough a bay seems to have developed westward up the St Lawrence trough, during Beekmantown time. The Beekmantown was brought to a close by another uplift of the entire northern New York region. In the Theresa district this time gap was a long one during which 1000 feet or more of Beekmantown rocks were deposited in the Champlain trough, and a much greater thickness in other regions.

Through these early times then our district had a general slope of its surface toward the east, though with an intervening time of short duration during which the slope was to the southwest. There were three depressions, alternating with three elevations of the surface, though apparently the deposits of the third depression just failed to reach the district.

In the Champlain valley the Beekmantown is succeeded by the Chazy limestone formation, the two being separated by a slight unconformity, indicating that the Beekmantown was followed, as it had been preceded, by general uplift of the whole area. Depression was then renewed in that trough for the third time, and for the third time a bay was developed westward from it. This Chazy bay, however, seems not to have reached as far westward as the preceding Beekmantown bay, and certainly fell many miles short of reaching our district here.

The Champlain Chazy is divided into lower, middle and upper subdivisions. The typical Chazy rocks are limited to the Champlain trough and its prolongation north and south. This trough was separated from a much larger depressed area to the westward, by a land barrier, which prevented the passage of organisms from the one basin to the other. At the same time therefore in which the Chazy rocks were being deposited in the Champlain trough, other deposits, characterized by a different fauna, were forming to the west of them,

and the rocks of this group are known as the Stones River formation. During Chazy time the depression in which Stones River rocks were forming was encroaching upon northern New York from the south and west, and by the close of the middle Chazy this depression had become sufficiently extensive to involve our district here, and the deposition of the Pamelia formation commenced, the Pamelia being the local New York facies of the Stones River formation, and representing only a portion of its upper division. The tilting of our district necessary to permit of this invasion from the southwest, changed its former easterly inclination to a southwesterly one, over most of the district; but apparently this change of slope died out on the eastern edge of the Alexandria sheet, east of which lay the land area which separated the Pamelia basin from the Chazy basin; and this received no westerly tilt, but chiefly retained its old slope to the east. This in our view is the origin of the Frontenac axis, as the narrow isthmus of Precambric rocks which connects the main Adirondack Precambric mass with the great Canadian area of these rocks, and which passes through our district here, is called. It simply represents an axis of the old Precambric floor which became less depressed than the portions of the floor east and west from it. The Potsdam-Beekmantown-Chazy depressions sagged the district to the east, covering it with steadily increasing thickness of their deposits in that direction; the Pamelia depression sagged the district to the west, and in that direction the overlying deposits steadily increase in thickness. The Frontenac axis is the pivotal district between the two, where sagging was least and deposit thinnest. Subsequent erosion could thus wear away this thin cover and bring the Precambric back to daylight, along this line, as it has done, while yet the thicker cover, east and west, in part remains.

According to Ulrich the Pamelia formation is of age intermediate between the middle and upper Chazy of the Champlain valley, but little sedimentation having taken place there in Pamelia time; in other words while this region was subsiding and accumulating deposit, that ceased to subside. With the cessation of Pamelia deposition on the west, resulting in the unconformity between the Pamelia and Lowville, deposition was renewed on the east and the upper Chazy was laid down. In like manner the Lowville formation is but slightly represented in the Champlain valley, though well developed here, as if, with renewed subsidence here it again ceased there. Toward the close of the Lowville, uplift occurred on the northwest giving rise to the unconformity between the main mass of the Lowville and the Leray limestone. At the same time depression

began in the Champlain region, and what has there been called Black River limestone commenced its accumulation. This deposit consists of a small thickness of typical Lowville at the base, the equivalent of the Leray limestone at the summit, and intermediate beds which represent the Lowville-Leray hiatus of the northwest; while the Watertown limestone is lacking. With our suggested nomenclature this may still be properly called Black River, while on any other arrangement it could not be so called. The Mohawk region was close to the shore line throughout Black River time and received only the very thin, near-shore edge of the deposits of the group, never more than a few feet thick, often practically absent and varying much in horizon from place to place.

At the close of the Leray, uplift was widespread and the Watertown limestone is practically absent except in that locality, in strong contrast with the widespread occurrence of the preceding Leray. Then followed subsidence on the east with accumulation of the Amsterdam limestone, which is wholly absent on the west. Then ensued on all sides of the region the Trenton submergence; limestone quickly followed by black shale on the east so that the bulk of the eastern Trenton is of shale; the shale gradually encroaching westward, but the western Trenton, of the type locality and northward, remaining of limestone throughout. The black shale of the Utica followed, with northern New York more largely submerged than at any other period in its geologic history, the Grenville possibly excepted. Possibly the Adirondack island was entirely submerged. With the close of the Utica local elevations began to appear, and by the close of the Ordovicic much of the State was again unsubmerged. Since then most of northern New York has remained a land area. The appended chart will, it is hoped, aid in the understanding of these views.

	Watertown region	Trenton Falls	Mohawk valley	Saratoga vicinity	Champlain valley
	Utica shale	Utica shale	Utica shale	Utica shale	Utica shale
Trenton group	Trenton limestone	Trenton limestone	Dolgeville shale Trenton limestone	Trenton shales	Cumberland Head shale Trenton limestone
Black River group	Watertown limestone Leray limestone Lowville limestone	Leray limestone Lowville limestone	Amsterdam limestone Lowville limestone	Amsterdam limestone	Amsterdam limestone Black River limestone
Chazy group	Pamelia limestone				Valcour limestone Crown Point limestone Day Point limestone
Beekmantown group	Tribes Hill limestone		Tribes Hill limestone		Division C, D and E of the Beekmantown Tribes Hill limestone(?)
Saratogan	Theresa formation Potsdam sandstone	Little Falls dolomite	Little Falls dolomite	Little Falls dolomite Hoyt limestone Theresa formation Potsdam sandstone	Little Falls dolomite Theresa formation Potsdam sandstone

NOTE.— Parallel lines represent the greater, and dotted lines the lesser unconformities. Unbroken lines represent absence of breaks.

Dip of the Paleozoic rocks

It has just been stated that the Paleozoic rocks dip away from the Frontenac axis in both directions, and it is desirable to scrutinize the matter somewhat more closely.

In the southeastern corner of the Theresa quadrangle the base of the Leray limestone is at 600 feet altitude. The general line of outcrop of the formation runs across the mapped area in a west-northwest direction, and on the Cape Vincent sheet passes beneath the river level 247 feet. This is a drop in altitude of 353 feet in 27 miles, about 13 feet to the mile, in this west-northwest direction. In the direction of due west it is about 16 feet per mile, as nearly as can be calculated. Neither one of these, however, gives the direction of true dip, which lies somewhere between s. 30° w. and s. 45° w. At Adams, which lies some 30 miles somewhat west of south of the village of Theresa, three deep wells were drilled for gas some years ago, and the records of these wells are given by Orton.[1] Fairchild, who is familiar with the region, has also supplied me with data. Starting on ground whose altitude is approximately 600 feet above sea level, these wells reached the Precambric at depths of 915, 950 and 960 feet respectively. The Precambric surface is here approximately 315 feet below sea level, while at Theresa it averages about 400 feet above the sea. In the 30 miles then, this surface drops 715 feet, or nearly 24 feet to the mile. This however is the slope of the Precambric surface, which may or may not coincide with the dip, and in all probability does not. If the different limestones could be distinguished in the well records the data would be at hand for determining the dip, but this is unfortunately not the case. If the Paleozoic rocks thicken in that direction, the dip is somewhat less than the above figure; if they thin it is somewhat greater. At Adams the Potsdam and Theresa formations, 150 feet in thickness about Theresa, have disappeared. The other formations are present however and are unquestionably thicker than at Theresa. Beginning near the summit of the Trenton, the drill at Adams penetrated through 900 feet of limestone before reaching the Precambric. If we knew the thickness of the Trenton in our district here we should again have the necessary data, but all the upper Trenton lies to the south of the map limits, and the thickness of the formation has never been accurately measured so far as we know. It is certainly as much as 500 feet and may be a hundred feet more than that. We have then at least 800 feet of Paleozoic rocks here below the Utica, and perhaps 900. It seems therefore that the thickening of the upper

[1] N. Y. State Mus. Bul. 30, p. 457-58.

limestones at Adams, just about compensates for the disappearance of the Potsdam and Theresa formations there, and that the dip is substantially the same as the fall of the rock floor, or 24 feet per mile. At most there is a deduction of but 100 feet to be made, amounting to 3 feet a mile in 30 miles, and reducing the total to 21 feet per mile. If, as is likely, this is still not the direction of true dip, being too nearly due south, the figure must be somewhat enlarged, and in all likelihood it amounts to from 25 to 30 feet per mile, certainly not exceeding 35 feet.

It is of interest to note that this dip, and this slope of the Precambric floor, are much less than those worked out in the upper Mohawk valley by Miller and myself (Remsen and Little Falls quadrangles) where the dips approach 100 feet per mile to the southwest, and the Precambric floor underneath has a slope exceeding that of the dip by some 30 feet. The matter of the present dips is simply the sum total of tipping given to the rocks since they were deposited, by the various oscillatory movements to which each region has been subjected since; showing that the Mohawk rocks have been somewhat more tipped than those here. The matter of floor slope however shows clearly that the shore line in the Mohawk region had a somewhat greater cant than was the case here, producing more rapid overlap of the rocks there.

In the northeast portion of the Alexandria sheet the dip has flattened out to practical horizontality, Potsdam with overlying Theresa forming the river bluffs. Going east, down the river, the dip soon changes to the northeast, carrying these formations beneath the water and the westerly edge of the Beekmantown becomes the surface rock, beyond which, for many miles, the river flows through Beekmantown rocks, all with slight northerly dip. These are the deposits of the eastern basin, and received no tilt to the west.

ROCK STRUCTURES[1]

Foliation

Foliation is the name applied to the species of cleavage developed in rocks which, under compression, have wholly or largely recrystallized. The cleavage is chiefly due to the arrangement which the compression enforces on many of the recrystallizing minerals, which tend to develop in the shape of

[1] By H. P. Cushing.

leaves or needles; so that, in so far as the mineral particles have longer diameters, or scalelike shapes, these develop in the planes at right angles to the direction of compression and give the rock a tendency to split along them. Obviously a better cleavage will usually develop in rocks which consist of more than one mineral than in those composed chiefly of a single one, and in the former case a better cleavage will appear where there is large difference in the characters of the different mineral species than where this difference is small. Thus a quartz-mica rock, or a feldspar-hornblende rock, will be apt to have a much better foliation than a quartz-feldspar rock.

A rock in which a good foliation cleavage is developed, so that it tends to split rather evenly and readily is said to be schistose, or called a schist. When the foliation is less even, and less ready, gneissoid is the adjective, and gneiss the substantive employed. As a general rule certain sediments, such as shales and impure (or shaly) limestones and sandstones, recrystallize into schists, while pure sandstones and limestones, which recrystallize into pure quartz or pure calcite rocks, and consist chiefly of the one mineral, show little or no foliation. Igneous rocks are usually already crystalline, and in general do not recrystallize with as prominent a foliation as do many of the sediments, hence are more prone to form gneisses than schists.

Foliation in the Grenville rocks. The pure Grenville quartzites and limestones are now quite massive crystalline rocks with little or no foliation, though there is some development of fracture cleavage in the resistant quartzites, which is lacking in the more plastic limestones. Even the quite impure limestones show usually but little foliation. The impure quartzites have developed either pyroxene or mica on recrystallizing, usually the former, and this rock has poor cleavage while the latter become quartz schists. In the mass of Grenville rocks of varying composition to which the general name of the "schist series" has been applied, foliation cleavage is in general prominent. But even here rocks with considerable development of minerals of the mica type are relatively rare, and since such constitute the most prominently foliated rocks, their rarity militates against the prominence of foliation in the series, the bulk of which would be better classed as gneissoid, rather than as schistose. Some varieties of the amphibolites are quite micaceous and hence possess good foliation cleavage. The green schists and ordinary amphibolites usually show fair foliation only, and a general assemblage

of all the types of Grenville rocks of the district does not give the impression of a group of extra well foliated rocks. This is largely due to the comparative scarcity of micas, and of amphiboles of slender habit, in the series and the abundance of pyroxenes and of stout amphiboles. This again is a result of the prominently anamorphic character of the metamorphism.

The foliation of the Grenville rocks is parallel to the bedding. In the schist series rapid alternations of materials of somewhat varying composition is a feature, producing a very well banded structure, sometimes so fine as to somewhat mimic a coarse foliation.

Foliation of the granite gneiss. It has been shown that the Laurentian granite is characterized by frequent inclusions of older rocks, chiefly of amphibolitic types, and that there is also present much intermediate material, resulting from the soaking of the amphibolite with granitic substance, or from its actual digestion by the granite. The rock itself contains normally some mica or hornblende, and hence, through the greater portion of the mass these minerals are present in varying quantity, and the rock is susceptible of foliation development under the proper conditions. That such conditions have obtained is clearly shown, a foliation cleavage of varying prominence appearing nearly everywhere, though it becomes very obscure in those relatively small portions of the mass which consist solely of quartz and feldspar. The general rock is thus foliated but with foliation of the crude type which proclaims the rock a gneiss, rather than a schist.

The foliation structure of the granite gneiss conforms everywhere in dip and strike to that of the adjacent Grenville rocks. While this by no means excludes the possibility that the Grenville rocks may have been compressed and foliated prior to the intrusion of the granite, it does demonstrate that both sets of rocks have undergone compression in common, subsequent to this intrusion. It is quite possible that much of this compression was a result of the actual intrusion, and that the granite gneiss actually solidified with a foliated structure. This is not at all uncommon in great bathylithic intrusions, which, in order to make a place for themselves, must endeavor to shoulder aside the rocks previously occupying the space. This shouldering pressure exerted on the adjacent rocks under bathylithic, or deep seated, conditions, that is with a thick cover of overlying rocks, tends to give the rocks thus compressed a foliation which parallels the

margins of the bathylith, and hence boxes the compass in direction. At the same time the rock of the bathylith, while solidifying, may develop a similar and parallel foliation.

While it can not be affirmed that such results were not brought about in the region, it can be positively stated that, if so, they have been so disguised by subsequent compressive stresses that the effects of the two can not now be successfully disentangled. This is shown in several ways: (*a*) the microscopic study of the granite gneiss indicates that, to a considerable extent at least, its foliation is due to recrystallization rather than to original crystallization, in other words the rock has been much crushed and somewhat recrystallized under compressive stress, since it originally congealed; (*b*) these later stresses seem to have been severe enough to materially change the shape of the bathylithic masses, elongating them greatly in the northeast-southwest direction and correspondingly pinching them together in the direction at right angles to this; (*c*) instead of the foliation running around the bathyliths, with parallelism to the margin, it retains its general northeast-southwest strike throughout the region, independendently of these margins, so that either no such marginal foliation was ever developed, or else it has been practically eliminated by the subsequent compression; (*d*) later igneous rocks than the granite gneiss have also had a foliation developed as a result of compression, most prominently in the earlier ones, and with steady decrease in prominence in the later.

It thus appears most probable that the general parallelism of the foliation of all the Precambric rocks, and its substantial uniformity in direction throughout the region, is chiefly owing to compression of later date than that of the Laurentian granite intrusion. This appears increasingly true in going eastward into, and across, the Adirondack region. The rocks show steady increase in amount of metamorphism, in degree of mashing and recrystallization, in uniformity of foliation, and in obliteration of such possible structures as primary foliation. Some of this increase may be ascribable to greater thickness of cover, but the evidence of thoroughgoing compression of much later date than the Laurentian, is very clear.

Foliation of the later igneous rocks. The Alexandria and Theresa syenites seem closest to the Laurentian in age, among the conspicuous igneous rocks of the district. The Alexandria syenite shows cores of fairly massive rock, not foliated though with a considerable amount of crushing. But the porphyritic

border phase is considerably metamorphosed and converted into a thorough gneiss, with the augen (the uncrushed remnants of original large feldspar crystals) alined in the direction of the foliation. This also is coincident with the direction of foliation in the Grenville and Laurentian rocks. While it is true that the metamorphism exhibited by the syenite is not as severe in degree as that shown by the other two groups, it is clear that there was severe compression of the region at, or after, the time of syenite intrusion, and compression under quite similar conditions as regards overlying load.

The Theresa syenite does not appear so foliated as does the Alexandria, chiefly because of difference in composition, which shows itself mineralogically in the much slighter development of hornblende and mica, the rock consisting largely of feldspar. It also lacks the coarsely porphyritic phase. Foliation is therefore much less prominent, though the rock shows crushing and recrystallization in degree quite comparable with the other. It has therefore likely experienced compression of substantially equivalent amount and duration, but its composition prohibits good foliation development.

Picton granite. This, the latest of the early intrusives of the district, shows little or no foliation, and to the eye gives little evidence of crushing, as if the intrusion was wholly subsequent to the great squeezing of the region. The thin sections bear out this impression.

This evidence would seem to indicate compressive stresses applied at intervals through a considerable length of time during the region's very early history, with gradual cessation, and that the foliation structure in the Grenville and Laurentian rocks must be due to something more than the pressure and heat furnished by the intrusion of the Laurentian granites.

Joints

The clean-cut divisional planes, usually highly inclined, which occur in most rocks, are termed joints. While generally vertical, or nearly so, they may have any inclination. In a "joint set" the divisional planes show a close approach to parallelism, both in trend and in inclination. In most regions more than one set is present. When there are two, the usual condition is that they are approximately at right angles to one another. Often there are more than two sets as is the case in our region here. When four sets are present it is usually found that they are separable

into two pairs, each pair consisting of two joint sets at right angles to one another, and the joints of one pair bisecting the angles between the joints of the other pair. In such districts it is seldom the case that all four joint sets are exhibited in a single rock exposure, two or perhaps three of the four showing, rather than the whole number. In many, if not in most, regions where four or more joint sets occur, it is found that one pair tends to north-south and east-west directions, with another pair showing northeast and northwest trends. The joint planes often curve somewhat, so that the compass direction of a given set may vary through a considerable number of degrees. This tendency much increases the difficulty of discrimination between the different sets in districts where more than four are present, as is quite frequently the case.

In folded rocks the character of the jointing differs considerably from that found in rocks not folded. Since in our region here we have rock masses of each sort, Precambric rocks which have been greatly compressed and folded, and overlying Paleozoic rocks which are comparatively undisturbed, it will be convenient to consider them separately.

In the Precambric rocks. The diagram [fig. 5] presents a summation of the readings taken on the joints of the Precambric rocks of the district included in the maps. They are comparatively few in number, partly because of the comparatively small area which presents these rocks at the surface, and partly because the joints were found to be so irregular that no satisfactory readings could be obtained in many exposures. The rocks are not as abundantly jointed, nor are the joints as clear-cut as usual in the Adirondack region.

In closely folded sediments, such as the Grenville, joints are apt to be present as a result of compression, and to have their directions controlled to a considerable extent by the folds, or in other words by the strike and dip of the folded sediments. These have been shown to have a general northeast strike throughout the district, though locally varying in direction through more than 90°. The more usual direction however is n. 40° e.–n. 60° e. Two sets of joints are present which have the same surface trend, that of the rock strike, the one set controlled by the dip and having approximately the same inclination, the other inclined in the opposite direction, or to the southwest, and closely at right angles to the first

set. Figure 4 is an attempt to illustrate these relations. These two joint sets, both having the same strike as the Grenville rocks, are much the most prominent of the joints which these rocks show, and

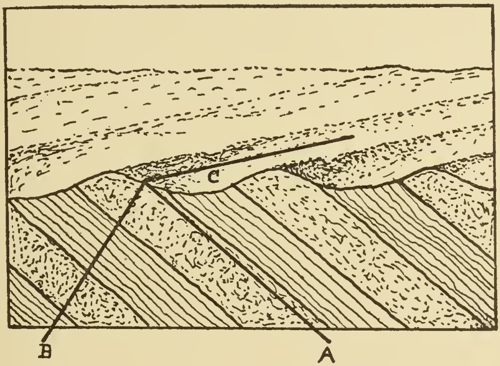


Fig. 4 Sketch and section of alternating quartzite and amphibolite bands of Grenville series, the quartzites forming low ridges on the surface. The line A represents the direction of the joints which follow the dip, the line B that of those at right angles to the first set, and C represents the direction in which both sets cut the surface

conspicuous at every good exposure of the Grenville schists or quartzites, though much less conspicuous in the limestones. The quarry face in plate 2 is on the dip joints, here steep, and the other set are quite flat and show well in the view, as does also a vertical set of northwest joints. So common are they that they soon came to be recognized as a matter of course, which it was superfluous to chronicle in the notebook. Hence the number of observations on joints striking n. 40° e.–n. 60° e. shown on the diagram [fig. 5] is misleading as to their abundance and importance. The com-

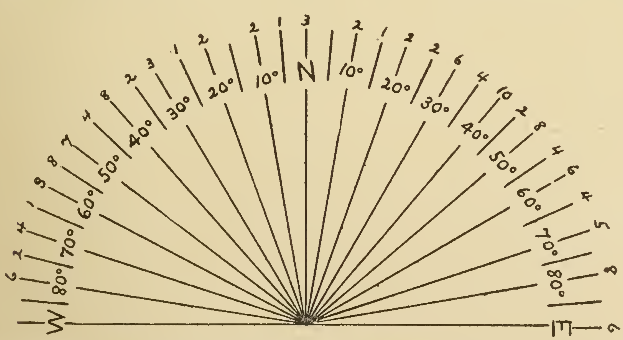


Fig. 5 Diagram to indicate the number of readings on joint directions in the Precambric rocks of the district for each 5° point of the compass, the outer row of figures giving this number, and the inner row the compass degrees, corrected for variation

paratively slight variation in the number of readings for all points between n. 30° e. and east is however a result of, and indication of, the swerving of these joints with swerve in the rock strike.

The foliation of the Laurentian granite gneiss, and of the gneissoid portion of the Alexandria syenite is concordant with that of the Grenville rocks, and in them these same joint sets are developed, though in a much less prominent way. In the more massive igneous rocks they are replaced by a set of vertical, northeast joints.

At right angles to the set, or sets, of northeast joints is a set with northwest trend, with planes nearly or quite vertical, and ranging from n. 40° w. to n. 55° w. in direction, 27 of the readings falling within those limits. A less conspicuous east-west set is also indicated by the 12 readings between n. 70° w. and n. 80° w., together with the 14 between n. 80° e. and e. As seen in the field also this set is more variable and less prominent than the northwest set. The number of northerly readings is not great, and is spread rather uniformly over 50° of compass range, coinciding with the impression given in the field as to the comparative scarcity and great irregularity of that joint set.

Notwithstanding the rather small number of total readings the diagram shows that 30 out of the possible number of 36 different 5° directions are represented. Nowhere in the field were more than four sets of joints noted in a given rock exposure, and all the joints showed considerable tendency to curve and vary in direction, leading to the belief that this spreading of the readings is owing to this variability and in no wise indicative of a great number of joint sets.

Locally the more rigid of the Precambric rocks, the quartzites and granites, are excessively jointed, the joints being very close spaced, chopping up the rock into small, angular blocks [*see* pl. 3]. In such places signs of slipping are usually to be made out. These so called "shear zones" result from readjustment under compression under conditions such that these rigid rocks fractured and slipped along the fractures, while those less rigid, the limestones for example, effected readjustment in other manner.

That the Precambric rocks were jointed prior to the deposition of the Potsdam sandstone is conclusively shown, firstly by the absence in the Paleozoic rocks of compression joints and shear zones, and secondly by the occurrence of joint cracks in the Grenville limestones which became widened by solution and in that condition were filled with sand as the Potsdam sands commenced to be deposited. In the few cases in the district where contacts between Potsdam and Grenville limestone are exposed these features appear [*see* fig. 1, p. 58] and are apparently widespread.

In the Paleozoic rocks. In the Paleozoic Rocks of the district, Potsdam to Trenton, the joints are vertical, or nearly so, and show also considerable variability in direction, though this seems not quite so pronounced as is the case in the Precambric. Figure 6 gives a diagrammatic summary of 280 readings on these joints, and shows again a spreading to all points of the compass, 34 of the 36 possible

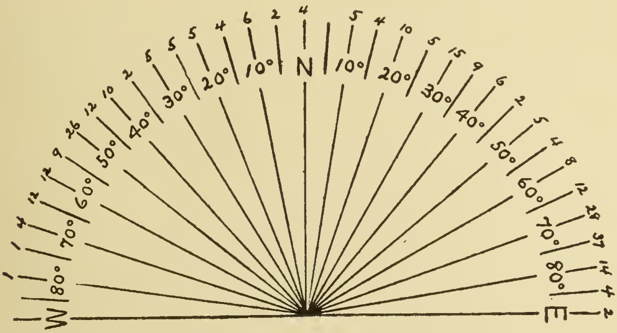


Fig. 6 Diagram, similar to that of the preceding figure, of the joints of the Paleozoic rocks

directions being represented. The great number of readings in the direction n. 70° e.–n. 80° e. constitutes the most prominent feature. The next point at which readings are concentrated is the n. 50° w. direction, but readings with this general trend are spread from n. 40° w. to n. 65° w., in other words these joints are somewhat less true in direction than those of the preceding set, which may however be regarded as extending from n. 60° e. to n. 80° e. A third direction of more abundant readings, from n. 20° e. to n. 40° e. is also shown, while the fourth direction, n. 10° w.–n. 30° w. is the least prominent of all. This last, however, is the one at right angles to the first, and most prominent, set. As thus outlined there are 99 readings for the first set, 81 for the second, 45 for the third and but 25 for the fourth. There remain 40 readings which lie wholly without these groups. It is to be noted that the mean directions of the four groups do not correspond with the cardinal points of the compass, but show a general deviation of 20° from them.

In the field the majority of the exposures exhibit but two good joint sets, though usually a third quite irregular set is present. With two good sets shown it is the exception that they are at right angles, and it is the east-west set and either the northeast or the northwest set with it, that usually appear. Often all three of these sets appear with lack of only the north-south set, and with the east-west set customarily the most prominent and regular. On bared rock sur-

faces therefore the joints ordinarily divide the exposure into rhomboidal, rather than rectangular blocks. In plates 15, 20 and 23 joints are well shown.

The limestones of the district exhibit, in general, more abundant, more regular, and more clean cut joints than does the Potsdam sandstone. The limestones moreover are all somewhat soluble in rain water and underground water, the Black River and some of the Lowville beds being preeminent in this respect. The glacial deposits over the district are in rather scant amount, there being much bare rock exposed, and much more only thinly coated with soil. On the bared limestone surfaces the widening of the joint cracks produced by slow solvent action of rain water which passes underground along them, is magnificently shown [pl. 26, 27], most impressively perhaps in the Black River beds but almost equally well in the upper Lowville. In many fields which might otherwise be available for pasturage, the cattle must be carefully excluded, otherwise they fall into, and become tightly wedged in these gaping fissures. During our field work we came by chance upon a poor, stray cow in such plight in the vicinity of Limerick, tightly wedged in a fissure of sufficient size so that the animal's back was well below the ground surface.

Down these widened joint cracks also the streams go underground, so that surface streams are infrequent in the Black River and upper Lowville districts. Beneath, this downward tendency is checked by the less soluble character of the remainder of the Lowville, on the upper surface of which these waters run along, eating away underground channels of considerable size in the soluble layers just above. In their early stages these channels are thoroughly roofed over, but as time goes on the roof tends to disappear, either by caving in because of lack of support by the widened channel underneath, or by slow dissolving away of the rocks above, thus bringing daylight down to the upper part of the tunnel. The matter will receive more detailed discussion when treating of the general drainage, but the details of the process and its varying stages are most excellently illustrated in the region [pl. 35–38]. While it is in many cases impossible to distinguish between preglacial and postglacial solution, it is nevertheless clear that much of this limestone removal is postglacial.

Folds

The rocks of the district exhibit various degrees of folding. The Grenville sediments are closely and intricately folded; the Paleozoic rocks show slight folding of Paleozoic date; and the same rocks

Bared surface of Leray limestone in field 1½ miles west of Sanford Corners, Theresa quadrangle, showing solution along joints. H. P. Cushing, photo, 1907

Bared surface of upper Lowville limestone, 1½ miles south of Sanford Corners, Theresa quadrangle, showing turf-filled joints. H. P. Cushing, photo, 1907

show occasional small surface folds, or buckles, produced since the ice sheet vanished from the region.

Precambric folding. It has been shown that the Grenville beds are now found for the most part in highly inclined condition, dips of less than 45° being relatively rare, while those approaching verticality are common. Averaging the dips of the entire formation would give a result of at least a 55° to 60° dip. It has also been shown that the dip is not everywhere in the same direction but that, with the general direction of strike to the northeast-southwest, the dip, while prevalently to the northwest, becomes at times southeast. The southeast dips prevail over a belt of country some 4 miles in breadth in the Butterfield lake district of the Alexandria sheet. In the country lying south of this belt the dips are all to the northwest. In the other direction the Grenville is badly cut out by the syenite and granite of the Alexandria and Picton bathyliths, but such as remains shows very steep to vertical dips, chiefly to the northwest. The highly tilted condition of the rock series, and these changing dips seem certainly indicative of folding. Moreover many exposures exhibit small folds of exceedingly compressed type, often accompanied by extreme plication. It is reasonable to suppose that these are merely secondary, or minor, folds superimposed upon folds of much larger scale.

In order to demonstrate the presence of these larger folds it is necessary that the order of superposition of the various Grenville beds should be worked out, and in the early stages of the field work it was hoped that this might be done. It is possible that it might have been successfully accomplished had large scale maps, say 4 inches to the mile, been available. But the structure is so complicated, the dips so steep, the folds so compressed, the series so greatly cut out by the igneous rocks, or so modified in character by them, and so much of the territory is yet covered by the Paleozoic rocks, that no certainty as to the Grenville succession could be arrived at with the maps in hand. Certain suggestions may however be made.

Inspection of the maps will show that the Indian river, from Theresa northward to the point where it passes off the Alexandria sheet, follows a broad belt of Grenville limestone, averaging somewhat more than a mile in breadth. Except for being much cut up by granite dikes and stocks, it is quite pure limestone. The dips are steadily to the northwest, and flatter than the usual Grenville dips, averaging about 45°, and hence indicating a thickness of about 4000 feet for the limestone. A few miles to the northward,

on the Alexandria sheet, what appears to be a quite similar broad belt of limestone borders the west side of Butterfield lake. It is however so much concealed by overlying Potsdam sandstone that some uncertainty attaches to its extent and purity. But it has a breadth of outcrop quite comparable to that of the Indian river belt, and *seems* to consist chiefly of pure limestone. Its dips are prevalently to the southeast, and somewhat steeper than in the previous case, averaging 60°. This means a thickness substantially the same as in the other case, and strongly suggests that the two are parallel outcrops of the same great limestone belt, and that, since they dip toward one another, the structure is synclinal. If this be the true interpretation then the schists, amphibolites and quartzites which lie between the two limestone belts, rest on the limestone and hence are younger, with the rather massive quartzites about Sixberry and Millsite lakes as the youngest of all; while the schists to the northwest on the Alexandria quadrangle, and to the southeast on the Theresa quadrangle, underlie the limestone and are older. Figure 7 will illustrate the suggested structure.

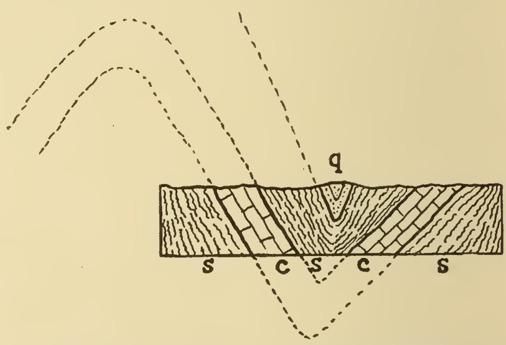


Fig. 7 Section to illustrate the structure suggested by the Grenville rocks, on a scale of 4 miles to the inch; s=schists, c=crystalline limestone, q=quartzite

There are, however, two alternative views in regard to this structure which may be held. It is possible that these two thick limestone masses may be separate beds, the one overlying the other and separated from it by the thickness of schist and quartzite which lies between. This involves the assumption that the series, though greatly tipped, is not folded and hence that no bed is cut by the present surface along more than one line. Since, however, small folds are certainly present in considerable number, the changing dips indicate the presence of greater ones, and as we have here two great lines of limestone outcrop, the rock showing much the same

thickness in each, and the two dipping toward one another, this supposition seems improbable in high degree. There seems no direct evidence for it and much against it.

The other alternative is that the structure here is anticlinal instead of synclinal. This is a possible interpretation of it in spite of the fact that the two limestones dip toward one another. Long continued and severe compression may so closely compress rock folds as to cause them to pass into the fan fold type as illustrated in figure 8. Such folds are so pinched that vertical dips prevail centrally, along the axes, and the dips farther away converge toward the axis in the anticlines, instead of in the synclines as in the previous case. In that also the dips flatten in the vicinity of the axis of the fold, and pass from one direction to the other through the horizontal, instead of through the vertical, as in the fan fold. In repeated instances, and in many localities, in the Grenville rocks of northern New York, the writer has observed that change in dip has taken place through the vertical instead of through the horizontal, and this seems to imply a condition of very close folding in the Grenville rocks at many and widely distributed points. In this especial case the dips change from the northwest to the southeast through the vertical in the schists northeast of Millsite lake, but with some comparatively flat dips in the interbanded quartzites north of the lake. At the same time the schists become greatly contorted and puckered. Millsite lake seems to lie closely along the axis of the fold. The section shown in figure 9 was sketched from an exposure ½ mile northeast of Millsite lake.

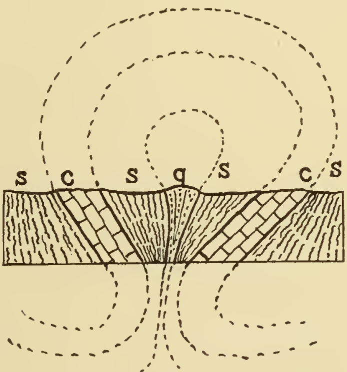


Fig. 8 Section similar to the previous, surface outcrops, dips and scale the same, on the assumption of fan fold structure

Fig. 9 Exposure of Grenville rocks ½ mile northeast of Millsite lake, showing sharply folded quartzite q-q, with a pinched in thin limestone between the quartzite limbs, l, the quartzite succeeded on the left by hornblende schists, s, and very schistose mica schist, ms, the dip being vertical or nearly so throughout

The structure here is definitely anticlinal, though that is no indication of similar structure in the main fold, since minor folds on its flanks must consist of both anticlines and synclines. It will serve, however, as a sample of many similar exposures in the district which show clearly that the series is folded, and that it is closely folded. It also well illustrates the closely compressed conditions, steep dips, and minor folds which prevail in the vicinity of the axis of the supposed fold.

The writer's opinion is that the structure here presented is synclinal, similar to that depicted in figure 7. The discussion, however, serves to present the lack of certainty which prevails, and the possibility that the structure is of precisely opposite character. Either one indicates folding, but one precisely reverses the order of rock succession of the other.

It is also thought probable that the heavy quartzite along the axis of the supposed fold is the same stratum as the even more massive looking quartzite of Grindstone and Wellesley islands. If the structure be synclinal, as supposed, this quartzite is the youngest Grenville formation of the mapped district, but if anticlinal it is the oldest. If these two quartzite belts do represent lines of outcrop of the same quartzite formation, there should be an additional line of outcrop of the thick limestone somewhere between the two, in the near vicinity of the river. This does not appear but its absence is not a fatal objection to this interpretation of the structure, since the Grenville rocks there have been completely cut out by the granite of the Alexandria bathylith, and it is impossible to say what may have originally been there.

In summation it may be said that the Grenville rocks are greatly tilted, suggesting strongly compressive folding, and frequent small folds occur. Two belts of thick limestone and two of thick quartzite suggest a single formation of each in folded condition. Study of the dips suggests that this folding is of a certain type, but it is possible that, owing to very intense compression, the structure is just the reverse of that suggested. It has not proved possible to determine the order of succession of the various formations composing the Grenville, and to use that succession as the key for unraveling the structure, as is the usual method in folded rocks. Instead the attempt has been made to decipher the structure and from that to determine the order of succession, but with only indifferent success.

Paleozoic folding. While the Paleozoic rocks of the district show but a trifling amount of folding, it is of interesting nature

and to a certain extent at least is due to the pivotal situation of the region with respect to the early Paleozoic warpings, as has already been shown. In general the rocks lie, in nearly flat attitude, on the worn surface of the sharply folded Precambric rocks. Over most of the district a low, southwesterly dip prevails; locally, however, the dip steepens to 5° or more, and dips occur in all compass directions. A strong westerly dip in the rocks along the Black river just above the bridge at Brownville is well shown in plate 28, and the dip is to the north, into the bank, as well, rock layers on the south side of the river lying some 10 feet higher than their equivalents on the north bank. In plate 24 a rather steep northerly dip in the Black River limestone at Watertown is shown, and in plate 21 a similar easterly dip in the same formation at another locality. These are samples of what is a matter of common occurrence all over the district. The areal mapping plainly brings out the presence of a series of folds which trend somewhat to the east of north. It also shows that the present stream valleys of the region in large part trend with these folds and chiefly follow the anticlines, while the synclines constitute the higher ground between.[1] Examples are the valleys running south from Theresa and from Evans Mills on the Theresa sheet; the French creek valley and the Chaumont valley on the Clayton sheet; and the Clear lake-Butterfield lake-Black creek valley on the Alexandria sheet; but there are many others of minor importance.

In addition to these nearly north-south folds there is a second set, about at right angles to the first, trending somewhat to the north of west, in parallelism with the Frontenac axis which is itself a fold of this group, the axial and most prominent one. Though mostly of minor importance, these folds are likely earlier than the others, and in part at least owe their existence to the warpings and tiltings of the region in early Paleozoic times, when it oscillated up and down, with tipping now to the east and now to the west. The Frontenac axis appears to be the major warp of this series, and the others are minor corrugations, grouped about it and diminishing in importance with recession from it.

[1] An anticline is the upward folding of rock layers into a long and relatively narrow arch; a syncline, the downfolding into a similar trough. Where erosion has removed the upper portion of such folds a worn off anticline is readily recognized on an areal map since it will show an older rock centrally, followed by successively younger rocks in the same order on each side; while an eroded syncline will show a younger rock in the center, followed by successively older rocks on each side. Thus the French creek valley, south of Clayton, shows Precambric rocks centrally, adjoined by Potsdam on each side, Potsdam adjoined by Theresa and that by Pamelia limestone, and the structure there is anticlinal.

In addition to the evidence which the general stratigraphy of the region furnishes as to the early date of some of this warping, evidence which has been already set forth, it also appears that the Potsdam and Theresa formations are somewhat more folded than are the overlying limestones, implying that they were somewhat folded prior to the deposition of the limestones. This is best shown in the district southwest from Clayton, along the valley of French creek, where the Potsdam is arched up into a prominent dome, even to the extent of bringing up the Precambric. The dome falls away to the south with rather steep dip, there is scant room for the Theresa formation between the south margin of Potsdam outcrop and the Pamelia front just beyond, and this Pamelia inface passes across the line of prolongation of this fold to the south yet shows no sign of being affected by it, being precisely the same cliff of horizontal limestone that it is to the east and west of this line. It is of course possible that a fault lies between, but the faults of the district are infrequent and insignificant, so far as known, so that the supposition seems unlikely, and the evidence seems to clearly point to folding and subsequent wear, during the long time interval between the close of Theresa and the beginning of Pamelia deposition. Evidence of less distinctive character but of the same kind is also forthcoming elsewhere.

Two series of low folds intersecting at right angles result in producing maxima of elevation at the intersections of arches and of depression at trough intersections, with intermediate conditions where trough of one set meets arch of the other. In other words the axes of the north-south folds are themselves folded by the east-west folds, producing elevated domes along the arches, and depressed basins along the troughs. A prominent feature of the areal maps is the considerable number of outliers and inliers of the various formations there shown.[1] The abundant Potsdam outliers on the Precambric are more largely due to the irregularity of the floor on which the formation was laid down, than to the subsequent folding. But

[1] Along the southern margin of the Theresa sheet are shown a number of patches of Leray limestone, lying to the north of the main line of outcrop of the formation, and entirely surrounded by the older Lowville limestone. The Leray limestone formerly extended over the entire district, and has been worn away from much of it, these representing outlying patches or residuals left behind in this general process of removal, hence known as outliers. Inliers on the other hand are patches of an older rock entirely surrounded by a younger, such as the Precambric by French creek south of Clayton, or the Lowville near Threemile Bay and Threemile Bay creek, on the Clayton sheet. These are much less common than outliers and are strongly indicative of a warped upper surface of the formation constituting the inlier.

Lowville limestone, capped by Leray limestone, at Brownville, extreme southwest corner of Theresa quadrangle. View looking northeasterly, across the Black river and upstream, showing the westerly limb of one of the low folds which characterize the Paleozoic rocks. The water is slack water, back of a dam, hence the river surface is horizontal. H. P. Cushing, photo, 1908

in the case of the other formations the great majority of the outliers are owing to wear on rocks of this folded type. The numerous outliers of Leray limestone on the Theresa and Clayton sheets chiefly mark the positions of basins (points of intersection of synclines of both series of folds), the dips being everywhere in toward the center. Similarly the Lowville inliers which Ruedemann has mapped on the Clayton sheet, north of Threemile and Guffin bays, mark the summit of domes (intersections of anticlines) with dip outwardly from the center. In the case of some of the outliers however, those of the Theresa formation on the Potsdam west of Theresa for example, the dome structure instead of the basin structure is exhibited, the outlier showing no prominent inface, and with dip outward from the center. The domed structure often shows excellently elsewhere, as for example in the Theresa formation at Orleans Four Corners (Theresa sheet) where the upper surface of a single massive layer of the formation protudes above the soil as a low, shallow dome, dipping outwardly in all directions. Many other examples might be cited and, owing to the abundance of rock exposures in the district the evidence of these structures is unusually clear, and it is quite certain that these two sets of low, cross folds occur.

Postglacial folds. There are in the district at least a half dozen examples of low folds, or buckles, of the surface rocks, which are of very recent origin. Though they form only a minor structural and topographic feature, they are rather unusual and the interest attaching to them is out of all proportion to their size and frequency. The writer has noted three of them in the limestones, Lowville and Pamelia, and Professor Fairchild has called his attention to two others. In addition at least one occurs in the Potsdam sandstone. The limestone folds seem all to conform to a common type so that a description of one of them, and of the one in the Potsdam, will answer every purpose.

The Potsdam fold occurs 2 miles south of Chippewa Bay, in the northeastern portion of the Alexandria sheet, is near the roadside and easily visible from it. It is 40 yards long, trends n. 28° w., and a view of it, taken at the south end, appears in plate 29. It rises sharply from the surface of an extensive plain, underlaid by nearly horizontal sandstone, with but a scanty soil covering and much bare rock exposed. The fold is of bared rock with beautifully glaciated surface, whose striations demonstrate that the buckling has occurred since the glaciation. The central portion is buckled up about 12 feet. The photograph clearly shows that, owing to compression, the rocks

were bent upward until, the elastic limit being exceeded, the fold snapped along the crest, furnishing relief to the bent flanks and permitting them to straighten. In the rock here only a single set of good joints appears, and this runs at right angles to the axis of the fold separating it into a series of transverse blocks. On bending, these seem to have fractured individually instead of collectively, so that the axial fracture does not coincide in the different blocks, but departs from the median line, now on one side and again on the other, as illustrated in figure 10, giving rise to the dovetailing of slabs along the crest, so well shown in the photograph.

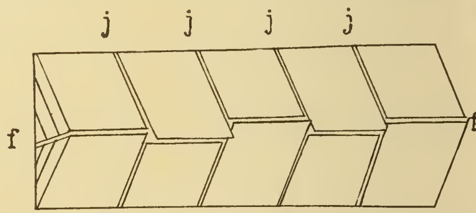


Fig. 10 Plan of fold in Potsdam sandstone, j-j-j=joints; f-f=fracture along crest, illustrating the manner in which the fracture shifts laterally in the different joint blocks, causing overlap of the rock edges along the crest.

One view of one of the folds in the Lowville limestone is shown in plate 30. The greater part of this fold is covered with soil, but centrally it has been stripped and a small amount of rock removed for local use. It seems to have about the same length as the previous one, and to be buckled up about the same amount. Its axis trends to the northwest. The rock is more closely jointed than in the Potsdam fold, and with two good sets present, one of which trends northwest with the fold, as the view clearly shows. Fracture then was unnecessary in this case and readjustment took place by utilization of these northwest joints, and instead of being actually folded, as might be judged from the photographs, the displacement really has the character shown in figure 11, as sketched on the spot.

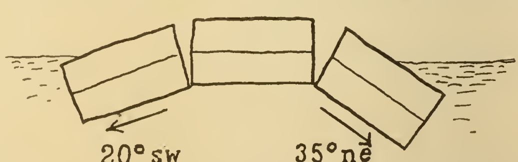


Fig. 11 Diagram to illustrate the arrangement of the joint blocks in the Lowville fold shown in plate 30 The central block lies nearly horizontally, the adjacent ones tipped in the directions and by the amounts indicated.

Small postglacial folds of similar type have been described by a number of authors and from various localities, and they have resulted from several different causes. Gilbert, after seeing some of

Postglacial arch in Potsdam sandstone, 2 miles south of Chippewa Bay, Alexandria quadrangle. The rock surface is glacially polished and shows the later date of the arching. The ruptured crest, and the dovetailing of slabs along the crest are also shown, and the set of cross joints. H. P. Cushing, photo, 1908

Postglacial fold in Lowville limestone, 1 mile west of Sanford Corners, Theresa quadrangle, looking northwest. The prolongation of the arch under cover as a topographic ridge is also shown. H. P. Cushing, photo, 1907

the limestone folds in this district, as well as others in shales in western New York and Ohio, demonstrated that they were superficial and postglacial, and attributed them to "horizontal expansion of superficial strata, consequent on postglacial amelioration of climate."[1] The writer does not question the correctness of this explanation as applied to the folds in shales and shaly rocks, which Gilbert describes, but is not so sure as to its adequacy in the case of quite massive, rigid limestones such as the Lowville, and is especially doubtful of it as applied to a well cemented, massive sandstone like the Potsdam, which is an exceedingly rigid and resistant rock. Postglacial climate is no warmer than was preglacial climate. Unless therefore the weight of the overlying ice was sufficient to cause some lateral spreading of the rocks, at the same time that it was producing contraction in them by lowering of their temperature, postglacial warming would merely reexpand them to their preglacial condition. There is no question as to the competency of the ice weight to produce lateral spread in shales and shaly rocks. Many shales are known to spread and to give rise to buckles under much smaller pressures, hence the cause suggested by Gilbert would seem ample to account for the results. But the pressure necessary to produce spread in a massive, rigid limestone is quite another matter, and that required in the case of such a rock as the Potsdam sandstone is of a still higher order. The weight of an ice sheet 1 mile thick would be equal to that of from 1700 to 1800 feet of average sedimentary rock. We do not know the thickness which the ice attained over this region but even the supposition that it was much more than a mile thick does not greatly enhance our figures of rock thickness. Are such pressures, even if applied continuously for a long time, sufficient to bring about lateral spreading in such a rock as the Potsdam? So far as known to the writer there are no direct, positive data which warrant a definite answer to this question. It is certain, however, that at such depths below the surface such rocks are abundantly fissured, are often porous, and permit free passage of fluids. This certainly suggests that they are not under sufficient weight to close up cracks.

If, however, this pressure due to the ice load could be reinforced by pressure from some other source in sufficient amount, the necessary lateral spreading could be brought about. A

[1] Gilbert, G. K. Am. Ass'n Adv. Sci. Proc. 35:227; 40:249. Am. Jour. Sci. ser. 3, 32:324.

The writer is under great obligations to Dr G. K. Gilbert, J. C. Branner and H. F. Reid for references to the literature and for personal discussion of these folds.

very likely source of such additional pressure is to be found in the well known oscillations of level which the district has undergone preceding, during and since glaciation. The general district has increased its altitude by some 400 feet since the ice disappeared from the St Lawrence valley, and this change is simply the last of a series of oscillations. Furthermore these movements were of the nature of warps, the changes in level not being everywhere the same, but of varying amount. Such warping must bring about compression in some tracts and stretching in others. The contraction produced in the rocks by the cooling of the ice sheet would likely have manifested itself in mere slight widening along the joint cracks, and side compression brought about by warping may have sufficed locally to close up these widened joints. In such case postglacial increase of temperature might well tend to cause buckling of the rocks. The warping is of such nature that it would tend to produce thrust from the northeast, and it is to be noted that these folds trend northwest, as should be the case on this hypothesis.

There at once arises, however, the further question as to whether the compression consequent upon warping may not have been perfectly competent to cause the buckling, entirely independently of any effect which the ice may have had, and this seems to the writer very probable. Dr Reid, in correspondence, states his belief that "we must fall back on the general explanation that movements of the crust are in progress which have produced these bucklings." Dr Branner expresses similar views. In any case, until it has been shown that lateral spreading may be produced in rocks of this resistant type by load no greater than that of the ice sheet, some doubt must attach to the competency of Gilbert's hypothesis as applied to these special cases.

Faults

Faults of considerable magnitude and importance have not been noted in the district, and the fairly accurate areal mapping which the abundant rock exposures render possible, indicates that no such are present, at least in the Paleozoic rocks. Small faults appear, however, in considerable number in all the rocks and are apparently of different age.

In the Precambric rocks. Small faults, with dislocations of from a fraction of an inch to a few feet occur in a great number of localities in the Precambric rocks, as already pointed out by

Smyth.[1] The numerous dikes, chiefly of granite, which everywhere cut the Grenville give every facility for determining their presence. They are in great number but for the most part of very trifling displacement. Similar faulting locally in the Paleozoic rocks suggests that this faulting is of Paleozoic date, but the much greater number of faults noted in the older rocks indicates some Precambric faulting at least, and of this there is direct evidence in some instances. The hand specimen shown in plate 5, lower figure, presents an adequate illustration. The rock is a well banded, acid Grenville gneiss, consisting chiefly of feldspar and quartz and seems certainly a sediment, a metamorphosed shaly sandstone. The bands vary in color from a light reddish to a blackish red, and are very plain, though without sufficient contrast to photograph clearly. They are parallel to the bedding and seem certainly to represent original lamination in the rock. Shearing has occurred, with development of fracture cleavage, principally at a high angle with the bedding, but with secondary fractures which rudely follow it, and along many of the former minute slips of the rock have taken place. These old cracks are now solidly welded up with secondary minerals, black in color, except for an occasional, shining pyrite crystal, and it is this secondary filling which furnishes the evidence for the date of the deformation and gives the chief interest to the rock. Pyroxene, hornblende and black mica (biotite), stated in order of abundance, are the minerals composing the filling, their grain somewhat coarser than that of the rock. They are of the same types as the minerals of the Grenville green schists. They argue for fairly deep seated conditions at the time of the deformation. The fractures show that the rock was above the zone of flow, but the minerals, the pyroxene especially, indicate anamorphic conditions and point to deformation in the lower part of the zone of fracture. Such faulting seems not only of Precambric date, but to have preceded the greater part of the long, Precambric erosion interval. Its date is made quite certain by the numerous dikes of Picton granite which cut the schists, the granite being younger than the filling of the shear zones.

There are also frequent shear zones in the Precambric rocks, zones of no great breadth but of considerable linear extent, along which the rock is shattered into quite small blocks by a multitude of close spaced joints, and along which some faulting has certainly taken place, small slips along many planes. No such shear

[1] N. Y. State Geol. 19th An. Rep't, pl. 15.

zones have been noted in the Paleozoic rocks, and the deformation which gave rise to them seems certainly of Precambric date, though later than that previously described since the rocks were under less load, hence nearer the surface.

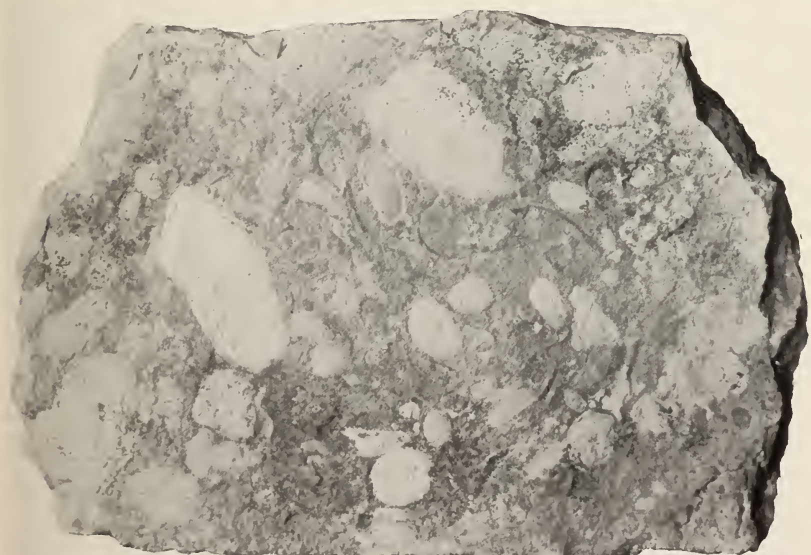
In the Paleozoic rocks. Frequent faults of small throw may be made out in the Potsdam sandstone. The red and white banded stone which constitutes the lower part of the formation on the Alexandria quadrangle is excellently adapted to display them, and a magnificent exhibit of them is given on the bare rock surface of the large Potsdam outlier which lies between the railroad and the north end of Butterfield lake. Here over a considerable area the faults are spaced but a few feet apart, and though the throw seldom amounts to as much as a foot, and is frequently only a fraction of an inch, the combined displacement of the whole must be quite considerable, as there are hundreds of them. For a hand specimen from this locality, showing one of these faults see plate 31, upper figure. All noted are normal faults of slight hade. The fault planes are filled with sand grains in all respects like those of the rock itself and as thoroughly cemented, which would seem to indicate that the faulting occurred before rock cementation was far advanced, so that the grains gave way individually instead of as sandstone fragments, whereas the latter would certainly be the method were faulting to take place in the rock now. Cementation subsequent to the faulting has thoroughly indurated the whole.

The bulk of the formation is rather uniformly colored and hence not so well adapted to display faulting of this type, and it is not certain whether it occurs in it or not.

There are also occasional small faults of a later type in the Potsdam, the fault planes remaining as open cracks, with sandstone fragments in the fault breccias. A small fault of this type appears in plate 12.

In the limestones a few faults have been noted whose throw amounts to several feet. The best example seen by the writer is in the lower Pamelia limestones of the Pamelia inface, 2 miles east of Perch lake. The section here shows the basal, black, fossiliferous limestones, overlaid by a thickness of some 15 feet of thin bedded, earthy limestone, followed in its turn by massive blue limestone with interbedded gray magnesian layers. These upper massive limestones are faulted down against the earthy limestone, the fault bearing n. 30° e, downthrowing to the east and with a throw of some 20 feet.

Plate 31



Upper figure. Hand specimen of faulted Potsdam sandstone, nearly natural size. The rock is red, with white streaks, and the fault plane is filled with white, thoroughly cemented sand.

Lower figure. Hand specimen of basal, Lowville conglomerate from near Depauville (Clayton quadrangle). The pebbles of fine limestone mud, of dove color, weather prominently white, as compared with the remainder of the rock surface. H. P. Cushing, photo

Ruedemann has mapped two small faults on the Clayton and Cape Vincent sheets and furnishes the following description:

In Chaumont village (Clayton sheet) is a small outlier of Trenton limestone, immediately to the west of which, and at the same level, is Watertown limestone. The relations are best seen about the viaduct on the Depauville road and along the railway immediately to the east. Under the viaduct is Watertown limestone. Along the railroad is Trenton at the same level, with a cut which shows steeply dipping Trenton, the dip being away from the Watertown and apparently due to drag on the downthrow side of a fault. The fault downthrows to the east, with a throw just sufficient to preserve the small patch of Trenton on the downthrow side. Its trend is substantially parallel to the road, or about northeast.

On Carleton island (Cape Vincent sheet) the presence of a fault cutting off the small western promontory, which consists of Watertown limestone, is suggested by the depression which separates the promontory from the mainland, within which no rock shows, and which is faced by a rock cliff on each side, a high Trenton cliff on the main island side and a lower cliff of Watertown on the other. A small fault along the depression, with downthrow to the east, is thus indicated.

TOPOGRAPHY [1]

The present day topography is the result of erosional forces acting for long ages upon a land surface, which from time to time varied in altitude and which underwent climatic changes. The character of the erosion, and of the resultant topography are also conditioned upon the character, attitude and structure of the rocks comprising the region. We have some slight knowledge of the changes in altitude of the region. The climate has certainly varied much, both in respect to temperature and to humidity, with, in quite recent times, the climatic rigor of the glacial period. The erosional forces, as always, have been in part atmospheric, but chiefly those of moving water and ice.

During paleozoic times the region was, when not submerged, one of low altitude. It was uplifted somewhat at the close of the Paleozoic, and during Mesozoic time seems to have been worn down to a comparatively even surface of low altitude, in common with much of the eastern portion of the continent. During the succeeding Tertiary it participated in the general uplift of the same region, and its present relief is chiefly a product of Tertiary wear.

[1] By H. P. Cushing.

Paleozoic altitude and climate

During the Lower Siluric the immediate region was from time to time submerged, at other times was above sea level. During submergence there were neighboring lands. It is apparent that all were of low altitude. During emergence there was but trifling wear on the exposed land surface. During submergence the adjacent lands furnished but little land wash, though the Precambric rocks of which they were formed were capable of supplying great quantities of sand and mud under conditions of any freedom of drainage; and they were near at hand and of much extent. A small thickness of sand marks the horizon of the Pamelia-Lowville break, otherwise the formations are unbroken limestone, until the shales of the upper division come in; and these are more indicative of stronger currents in the marine waters, than of especially increased altitudes of the neighboring lands. The succeeding Oswego sandstone seems a continental, rather than a marine deposit and indicates freer drainage and somewhat greater altitude.

But little has been gleaned from the region itself as to climatic oscillations in these early times. The upper Pamelia was marked by a somewhat arid, and perhaps warm climate, as has been seen. Probably the same was true of the Oswego-Medina, though that lies outside our district. The Potsdam climate is a puzzle. Farther east, where the basal Potsdam consists largely of arkose, and where the Precambric underneath shows the same freshness and the same irregularity of surface under the Potsdam that it does here, we have expressed the opinion that the sandstone was a continental deposit, so far as the basal portion is concerned, and that the climate was arid. Here however, with the same character of floor, we have a pure sand deposit, instead of arkose. The unweathered character of the Precambric rocks, the absence of residual weathered material, except in very scanty amount in the most sheltered situations, and the general base-leveled character of the surface, seem to point to long continued wear under conditions of aridity and removal of disintegrated material by the wind. Under those circumstances however the residual products should be arkose, instead of pure quartz sand such as constitutes the Potsdam here. There is much more feldspar in the basal Pamelia sand than in the Potsdam, and even in that it is not in great quantity. We are unable to correlate this quartz sand with conditions of climatic aridity, and equally unable to explain the character of the Precambric surface, and the unweathered condition of the rocks, satisfactorily to ourselves, on any other basis.

During the remainder of the Paleozoic we know but little concerning the region here, except by comparison with other regions more or less remote from it. It may have been somewhat submerged during the Siluric, but certainly, for most of the time, it was a land area, and the small amount of wear which it experienced indicates that, for most of the time, its altitude was low.

Amount of erosion

The total amount of rock thickness which has been worn away since the region became a land area, can not of course be exactly determined, though it is thought that it can be approximated. To the south the Trenton limestone is overlaid by the Utica and Lorraine shales, and these by the Oswego sandstone and Medina shale and sandstone. These are all sufficiently near to make it in high degree probable that they were laid down over our district, especially since the source of their sediment must have been to the north and east. It is regarded as unlikely that they had any greater thickness here than they now show toward the south, but they may have been as thick. We have no evidence that any formations later than the Medina were ever deposited here, and even if so, the thickness would seem to have been small and the submergence brief. If therefore we allow to these formations the full thickness which they show to the south, we are likely exaggerating their thickness here and allowing a margin to account for any possible later formations which may have existed.

The deep wells which have been drilled at various points between this district and the Syracuse region, give the data desired. In the Monroe well at Baldwinsville the drill went through 1740 feet of sandstone (Medina-Oswego) and shale (Lorraine-Utica), reaching the top of the Trenton at 2240 feet. If we assume them to have been deposited over our district in the same thickness, and add the thickness of underlying rock (Potsdam-Trenton) we get 2600 feet as an outside measurement of the Paleozoic thickness here originally. In all probability this is considerably too high. There were 1200 feet of sandstone and 500 feet of shale above the Trenton in this well, and the full thickness of both was passed through by the drill. In the wells further north, as in Orwell and Central Square, less sandstone appears but the shales thicken to 700 feet. Since no certainty is possible our purpose is best subserved by a generous estimate, and an original thickness of 3000 feet of Paleozoic rocks here will be assumed. Where Precambric rocks are now at the surface, 3000 feet is regarded as the outside limit of the thickness

of overlying rock which has been worn away, from the close of the Siluric to the present. Where the various members of the Paleozoic form the surface rocks, erosion is correspondingly less, and since the Precambric is at the surface over but a small fraction of the region, the general erosion has been less than that figure. Considering the great length of time involved, this represents no great erosion, and seems to point to land of no great altitude for much of the time. It seems to be further demonstrable that at least one half of this erosion took place in Tertiary time, which argues all the more strongly for general low altitude during the preceding ages of the Mesozoic and later Paleozoic.

Original drainage

As uplifted at the close of the Siluric, and following the deposition of the Oswego sandstone, our area became the marginal portion of land masses to the north and the east, and in all probability possessed a gentle slope to the southwest. The original streams must have followed down this slope to the margins of the later Paleozoic water bodies of central New York, thus flowing in the direction of the rock dip, and at right angles to the strike. Having taken position they would commence to carve valleys, whose possible depth would depend upon the altitude of the land. Streams of this type are called consequent streams. With valley cutting in progress, tributaries to these original streams commence to develop, beginning as gullies in the valley sides, and steadily cutting headwards. Obviously they form most readily where the valley walls are weakest, and tend to remain in the weak rock belts, following their strike, hence with courses which make substantially a right angle with those of the original streams. Such streams are called subsequent, since their development must wait on that of the consequent streams. With a belt of weak rocks to follow, these subsequent streams may eventually become the chief streams of a region, diverting or "capturing" the headwaters of the old consequent streams. The Utica and Lorraine shales constitute such a weak rock belt in this region, with the great Ontario valley eaten out along it, the Adirondack highland blocking its extension further east.

With chiefly low lands, drainage adjustments would go on but slowly, and the drainage may have been considerably modified from time to time by tilting of the land, under these low altitude conditions. With the passage of time, however, it has come about that the chief streams of the region are now in subsequent position,

and there is little trace of the old consequent streams, though the streams running westerly, out of the Adirondacks, seem to represent the old heads of such streams.

Tertiary uplift

Evidence derived chiefly from without the district indicates that our region, in common with much of eastern North America, was worn down to a comparatively smooth surface (peneplain) of low altitude by the close of Mesozoic time. It then experienced considerable uplift, erosion was renewed and streams cut and widened considerable valleys in the weaker rock belts, while the more resistant rocks retained in considerable measure their original altitude, and give us the remnants of the old plain. Elevations of over 1500 feet are found on the Watertown sheet, immediately south of our map. On the Port Leyden sheet, next south, the altitudes reach almost 2000 feet, the district there forming a low plateau, capped by the resistant Oswego sandstone, between the Ontario lowland to the west and the broad valley of the Black river to the east. East of the valley the levels rise within a few miles to 2000 feet, in the westerly edge of the Adirondack platform, and from there continue to slowly rise eastward. The Adirondack highland, and the Oswego sandstone plateau, are regarded as remnants of the old peneplain surface, which as uplifted, was given a slight tilt toward the west, while the deep valleys of the region have been cut since the uplift and give some measure of its amount. Unless later rocks in considerable thickness have been worn away from the surface of the Oswego sandstone plateau, the amount of wear there has been very slight; yet this small thickness of removed rock represents the general erosion over the entire region from the close of the Ordovicic to the close of the Cretaceous, a wear so slight as to be only compatible with low altitude of land when the length of the time interval is considered.

Tertiary drainage

The Tertiary uplift of the region gave to the land an altitude in excess of that of the present. A partial measure of this excess is the difference in level between the Tertiary valley bottoms and those of today; but we do not know the depth of valley filling in this district and hence can not state the excess. Even before the uplift the streams had likely become adjusted to much their present relation, namely consequent streams flowing westerly

and northwesterly out of the Adirondack region, and southerly and southwesterly out of the Canadian Precambric region, and these streams diverted by the large subsequent streams in the Black river, St Lawrence and Ontario valleys; the Black along the overlap of the sedimentaries on the crystallines, the Ontario valley on the thick shales, and the St Lawrence on the limestones of the depressed trough, with bordering Potsdam and Precambric on both sides; hence each on a relatively weak rock belt. In these positions the Tertiary successors dug out their valleys. They mostly flowed as they do now, the important exception being in the case of the Ontario-St Lawrence drainage. The fold, or warp, of the Frontenac axis crosses this drainage line in our district. Even before being worn down to the Precambric this would make a natural rock barrier to the drainage, since the lower Ordovicic rocks are more resistant than the upper, and hence form a divide or col between waters flowing northeast, down the present St Lawrence valley, and waters passing west through the Ontario valley, the Black river forming the chief stream of the immediate region, as it now does. All writers on the district have considered that, in Tertiary times, the Black river turned westward into the Ontario valley. Wilson especially has considered the drainage of the immediate region in some detail in a most excellent paper, with much of which we are in entire agreement.[1] He points out that the St Lawrence lacks a definite channel in the Thousand Island region, going over the Frontenac axis at its most depressed point. With this we agree, but we do not coincide with his view that the Black river, in its course across the mapped area, is closely in its preglacial channel (the river below Carthage is here referred to). We are however in doubt as to where this preglacial channel was. Fairchild disagrees entirely with the view that the preglacial waters of the Black river went westward, and turns them into the St Lawrence valley below the col. His views are presented on pages 141–145. I dissent somewhat, preferring the view that the drainage went into the Ontario basin, but must frankly admit that I have not discovered the precise route followed, so that it seems to me that opinion in the matter must be held in abeyance, pending discovery of the actual old channel.

If the Frontenac axis formed a divide here in Tertiary times such divide should run across our district toward the Adirondacks, as a divide between streams going north and those moving

[1] Geol. Soc. Am. Bul. 15:236-42.

west. The presence of this divide, with its sharply cut ravines heading against it on both sides is to us one of the most interesting features of our district. It is most unfortunate that the maps of the quadrangles next east are not available so that it could be further traced in that direction. Inspection of the Alexandria and Theresa maps will show plainly its course across them. In the low grounds near the St Lawrence the ravine heads are not prominent, though the two lateral ravines into Cranberry creek valley from the east are good examples. But at Browns Corners, 4 miles southeast of Alexandria Bay, is seen the head of the first of a series of sharply cut valley heads with northeast trend. The next is at Plessis, dropping down sharply into the Clear lake-Mud lake-Butterfield lake valley, with a secondary sharp drop at the head of Butterfield lake. One and one half miles southeast of Plessis, on the extreme south margin of the Alexandria sheet, is the head of the Hyde lake-Hyde creek-Perch river valley, on the other side of the divide, belonging to the southwest drainage. Just east are two sharply cut ravines heading on opposite sides of a low pass across the divide, the valley of Crystal lake, which is tributary to the Mud lake valley, and the valley without present drainage, followed by the railroad and leading south into the Indian river valley on the Theresa sheet. This valley is somewhat more blocked by drift than the others and seems to have held a shallow lake. The Millsite lake and Sixberry lake valleys also head sharply against the divide on the north. They are however of somewhat abnormal type. Most of the other valleys mentioned commence as distinct but shallow, rock-cut trenches, which, after a short course, suddenly deepen to gorges with walls from 40 to 100 feet high. The Clear lake and Hyde lake valleys nicely illustrate this type. The lakes are at the heads of long valleys leading away from the divide. The Crystal lake, Sixberry lake and Millsite lake valleys, on the other hand are short valleys, tributary to others at the side, and they deepen almost at once, instead of having the preliminary shallow course. The view of the head of Crystal lake valley [pl. 34] gives an excellent idea of the general character.

Passing to the Theresa sheet, attention is at once directed to the considerable and deep valley, leading north past Theresa, the valley into which the modern Indian river breaks at that point, with production of falls and short gorge [pl. 32]. The valley itself heads 3 miles further south. Two miles to the west is the Hyde creek-Perch river valley, running southwest and heading

on the Alexandria sheet, as we have just seen. This parallel, but northerly-flowing Theresa valley plainly heads several miles south of the original line of the divide, in other words has pushed it south out of line by headward cutting of its valley. Its ability to do this was no doubt conditioned upon the weak resistance of the Grenville limestone belt there. Once the Potsdam was cut through, rapid headward cutting of the stream would be possible. From the present valley head a shallow valley runs southwest to Perch lake, and it seems clear that formerly this valley headed along the old divide, and was diverted, bit by bit, by the more advantageously situated stream flowing the other way. The minor tributary valleys from the east and west, between Theresa and the north margin of the sheet, are southerly trending valleys, southeast or southwest, and hence adjusted to a southerly, rather than a northerly flowing stream. The northerly flowing stream slowly captured and reversed the headwaters of the south stream, extending its capture through a distance of from 4 to 5 miles.

Northeastward from Theresa are a number of valleys heading sharply against the Potsdam mass which there forms the divide, and leading away from it to the southwest. These are located on belts of Grenville limestone, or of weak schist, and therefore are broader and less ravinelike than most of such valleys in the district. They are, however, comparatively narrow, distinctly rock walled, and with present flat-bottomed floors owing to drift deposits.

Here, in the northeast corner of the Theresa sheet, the divide runs off our maps to the east, and with maps of that district not yet available, its further course can not be traced. It, today, rises steadily in altitude in that direction, and is, as in Tertiary times, the divide between waters flowing north to the St Lawrence and west to the Ontario valley.

The Indian river of today, from Theresa south to the great bend north of Evans Mills, is flowing in reversed direction through what was then the valley of a small stream heading near Theresa and flowing south. Wilson's view is that at the bend it was tributary to a southwest stream, occupying the valley now followed by Indian river above the bend; and that their combined waters flowed south through the present West creek valley to the Black river. With our disbelief in the presence of the Black river there at that time, coupled with the fact that the West creek valley seems both to widen, and to deepen,

Plate 32

The smaller of the two gateways at Theresa through which the Indian river passes into the preglacial valley. The rocks are steeply dipping Grenville schists. H. P. Cushing, photo, 1907

northward, we are in doubt as to the correctness of this view. Certain it is, however, that the present course of Indian river is a patchwork of various preglacial valleys, the modern character of the course being most excellently shown at Theresa where the river drops 80 feet, from a shallow valley into a much deeper one, entering this on its east side 3 miles below its valley head, with cutting of a short, postglacial gorge in the old valley side.

Plateaus, terraces, scarps

With the streams cutting down valleys and exposing rock formations of varying age and resistance in their valley walls, and with the slow widening of the valleys, the stronger rock beds of the region tend to outcrop in cliff form, the scarps running across country in the direction of strike, and curving up the consequent valleys in the direction of dip. The stronger cliffs result where a more resistant rock overlies a considerably less resistant one, the more rapid wear of the underlying rock tending to keep a tolerably steep and precipitous cliff front. Where the differences in resistance are less, or where rapid changes in resistance occur, involving no great thickness of rock, low, subdued scarps are produced.

Furthermore, where an overlying formation is weaker than that beneath, rapid wear is checked at the upper surface of the lower rock, the upper rock is stripped away from it and a flat bench of varying breadth is produced, separating the cliff fronts of the upper and lower formations. In the large way, ignoring minor complicating factors, the general topography of our district is of this type: flat platforms developed on the surfaces of the hard layers, and cliff fronts which mark the descent from one rock platform to the next, the cliff fronts facing toward the old land area, in this case to the north, hence often called infaces.

The most prominent cliffs, and the broadest platforms of the district are those of the Potsdam sandstone, as it usually has considerable thickness, is the strongest or most resistant of the Paleozoic rocks, and more enduring than much of the Precambric, on which it rests. The Precambric topography has already been described, and this does not need repetition. The Potsdam is thickest where the underlying Precambric is weakest, the bulk of the remaining Potsdam rests on these weaker rocks, this being notably true in the case of the outliers. Potsdam cliffs from 20 to 60 feet high are abundant throughout the district, and are absent only where the underlying rock is granite and the Potsdam very thin. Broad Potsdam

platforms are well shown on both the Theresa and Alexandria sheets.

Though the Potsdam as a whole is strong, the uppermost beds, together with the sand beds in the basal Theresa, form a weak combination, in which the massive bed of the Potsdam summit is relatively strong. The overlying Theresa is also stronger than this weak zone, and hence the Theresa edges form rather prominent infaces, with these weak beds at their base; not infrequently also the strong summit bed of the Potsdam forms a narrow platform of its own, part way up the inface [pl. 33]. The Theresa rocks weather to iron stained crusts and their exposed edges have a thin bedded look, giving these infaces a peculiar and unmistakable look of their own. Above the base the Theresa shows rather rapid alternations of thicker and thinner bedded layers, the former somewhat more resistant, so that low infaces of these various layers are frequent throughout the Theresa country.

The sandy basal layers of the Pamelia formation, some 25–30 feet thick, constitute the weakest zone within our map limits, and are readily stripped away from the Tribes Hill underneath, while the overlying limestone is more resistant, so it is not surprising that the Pamelia cliff front is one of the most conspicuous topographic features of the district, a feature which the contour maps clearly bring out. In front lies a flat Tribes Hill platform. The cliff ranges from 20 feet to more than 100 feet in hight, but is usually from 50 to 60. Higher up in the formation the occasional very massive limestone beds form frequent low infaces of their own, as in the case of the Theresa formation. The Lowville differs but little from the Pamelia in resistance, and has no zone of weakness at its base, hence is not fronted by a prominent inface of its own, and is the only formation which lacks one. It has its own minor fronts, but these are of the same order of magnitude as those of the upper Pamelia beneath.

The Leray is a thin formation, but because of the massiveness of its beds, and the abundance of chert in its lower portion, it everywhere forms infaces with distinct characters of their own, of which the curious blocky type of weathering is the most conspicuous [pl. 20]. The 7 foot tier above also has a front of its own.

The thin bedded Trenton limestone is considerably less resistant than the Watertown, hence the Watertown platform in front of the Trenton inface is comparatively broad, especially when the small thickness of the formation is taken into consideration. Notwithstanding the weakness of the Trenton, its inface to the south of the Black river is far the highest and most commanding of the

North face of Theresa escarpment, 1¼ miles southeast of Clayton, looking west. Theresa dolomite on left, upper surface of Potsdam sandstone on right and in foreground. H. P. Cushing, photo, 1908

region. Only a little of this is within the map limits, in the extreme southeast portion of the Theresa quadrangle. Such Trenton as there is north of the river shows itself in rounded hills without prominent inface and this is its normal and usual character. The high cliff referred to is unusual and due to proximity to the Black river.

Minor modifications of these general features are produced because of the low folds of the Paleozoic rocks. The discussion of these has shown how low domes and shallow basins are thus produced in the rocks, resulting in the formation of outliers and inliers of the various formations, with their local infacing or outfacing cliffs; resulting also in a lobation of the general formational infacing fronts. As Ruedemann has stated these lobes are most conspicuous in the Leray fronts, an additional cause being there at work to accentuate them. Nevertheless they are primarily due to the folding, the other infaces showing similar, even though less conspicuous lobes. The topographic maps show these general features excellently.

The lowlands of our region today are chiefly the result of the stream wear during the Tertiary. The prominent rock infaces and platforms of the various formations are owing to the considerable differences in level between the low grounds and the adjacent uplands, and terrace broadly the ascents from the one to the other. These features, together with those of the drainage outlined above, were substantially what they are now at the end of Tertiary time. There are few northern regions in which the general topography is so little changed, and has its Tertiary features so little masked by subsequent Pleistocene changes as is the case here.

Lakes

The group of lakes in the southeastern portion of the Alexandria quadrangle, together with a few more of the same type in the district to the eastward, constitute one of the very interesting features of the district. Their interest arises in part from their localization; they are abundant in this restricted area and are scarce or lacking elsewhere. In some features they resemble the much more abundant, and more widely dispersed, lakes of central Ontario, as described by Wilson; in one respect they are sharply contrasted with them.

Wilson describes the Ontario district as characterized by a prominent cuesta front at the north edge of the Paleozoic limestones,

overlooking the Precambric areas to the northward. The drainage is to the southwest and passes from the Precambric into the Paleozoic limestone country, the streams deeply notching the cuesta front as they pass into it. Of the lakes he says: "In most cases the upper parts of these valleys, near where they pass through the cuesta front, form the basins of long, narrow lakes. The water seems in some cases to be held back by a drift dam, which partly blocks the lower part of the valley. Certainly in some cases, in all probability in most cases, the present lake basin is a rock basin and the existence of the present lake is due either to warping or possibly to differential erosion by ice.[1]"

In this district of Wilson's the Potsdam and Theresa formations are absent, the Pamelia, or Lowville, resting on the Precambric, forming a single cuesta front that is more prominent than those in our district. The lakes on the Alexandria sheet have their beds either on Precambric or on Potsdam, and the limestone front is more or less remote. They nestle in the extreme upper portions of the valley heads on the north side of the divide which runs through the region, and has just been described. They are in the extreme upper portions of the valleys of north-flowing streams, instead of occupying a special position in the valleys of southerly streams, as in the case of the Ontarian lakes, and in this lies their chief difference from those. Hyde lake, in the northern portion of the Theresa sheet, conforms more nearly to the Ontarian type, though in Potsdam instead of Precambric, and Perch lake seems the shallow remnant of another lake of similar type. The Alexandrian lakes, however, differ as specified, and herein lies also the reason for their localization. The old divide runs into higher ground passing eastward, and the relations of the rocks shift. The streams there rise in the Precambric and run northward into the Paleozoic rocks of the St Lawrence valley, while our lake valleys here commence in Potsdam and run north into Precambric.

Most of the lakes seem to be in rock basins, Crystal, Sixberry and Millsite certainly are, and Butterfield probably is. Crystal lake is entirely in Potsdam though its bed may be on the Precambric, and is walled by high and continuous sandstone cliffs, with the sharply cut valley head but a short distance back from the lake margin [pl. 34]. Sixberry, Millsite and Butterfield are partly walled by Potsdam, with characteristic cliffs, and with valley heads cut in Potsdam, but with their beds in Precambric [pl. 54]. The beds of the two latter are in large part in Grenville limestone. Six-

[1] *Op. cit.* p. 217.

Head of Crystal lake, 2½ miles south of Redwood, looking north down the lake. Cliff of Potsdam sandstone, characteristic basin wall, seen at right. Compare plate 51. H. L. Fairchild, photo, 1908

Bared surface of Tribes Hill limestone, 1 mile west of Lafargeville and close to the point from which plate 15 was taken. The joints run n. 70° e. and the view shows that some solution takes place along them even in this rock; in fact the stream is now flowing below ground and breaks out as a large spring at the base of the rock wall shown in plate 15. H. P. Cushing, photo, 1908

berry is surrounded by quartzite and granite and there is no known evidence of limestone in the bed.

Whether these basins were dug out by ice, or have resulted from warping, we are unable to say. In either case we can not see why no lake was formed in the valley which heads at Browns Corners, and is of identical type with the others. The extreme head of a valley up which the ice was moving would seem an unlikely place for it to dig. Solution of limestone may have aided in the formation of some of the basins. Though we are unable to account for them to our satisfaction, their localization seems to us unquestionably due to the localization of the especial type of valley heads in which they occur.

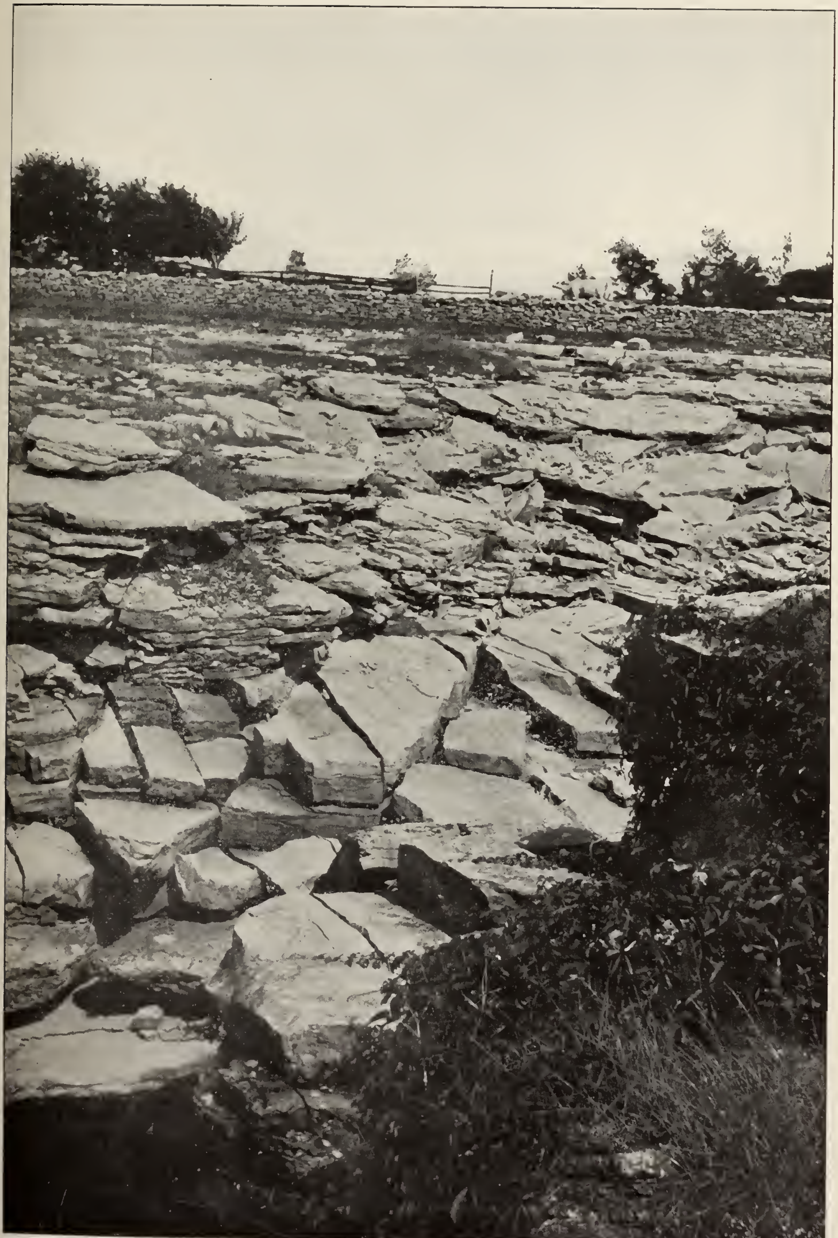
Underground drainage

It has previously been shown how, in the more soluble limestones of the district, chiefly the Black River and upper Lowville, rain water widens the joint cracks by solution, and much of the surface water of the district passes down through these fissures to underground flow [pl. 26 and 27]. The Leray limestone is more soluble than the Lowville and the chief underground drainage of the region is in Leray districts, the underground waters running along on the upper surface of the Lowville, slowly enlarging their channels by solution. But there are also underground waters in the Lowville the upper beds of which are more soluble than those beneath. Even in the Theresa formation similar action is at times seen. In plate 35 may be seen bared Theresa surfaces in the bed of a brook, with joints considerably enlarged by solution, sufficiently so to allow the water of the creek to entirely disappear through them, to emerge a few yards away at the base of the cliff shown in plate 15, the cliff being part of the rock wall of a somewhat filled Tertiary valley, that of the Chaumont river. During the spring floods the underground channel can not care for the entire flow, and part of it remains at the surface, flowing over the rock exposed in the view. In the Leray and Watertown limestone districts are many stream beds of bare rock, totally dry throughout the summer, with their waters underground, but showing plainly the incapacity of the underground channel to care for flood waters, which flow in part at the surface, and keep the beds thoroughly washed out. Examples of such are the creek coming into the Black river from the south at Felts Mills (southeast corner of Theresa sheet), and the bed of Philomel creek near Brownville. Much underground water comes into the Black river, all across the district.

With enlargement of the underground tunnel the roof tends to cave in, at first where thinnest, followed by gradual lengthening. In most cases the cover is thinnest toward the stream mouth and caving in begins there and works slowly upstream. In the case of the creek at Felts Mills, just referred to, the map shows Lowville limestone in its bed for a half mile above its mouth, beyond which the Leray forms the bed rock. In the Lowville for part of its course the stream is above ground, and the point where the formational contact crosses the stream marks the point of emergence from underground, and the slow upstream working of the roof cave in. In plate 36 is a rather unsatisfactory view of the caved roof of a small stream, unsatisfactory because no position of the camera which looked upstream could be obtained, and we are here merely looking across from one bank to the other, with the nearer bank somewhat hiding the view of the opposite one. The stream is a small one, fed by the underground waters of a Leray promontory of no great extent, but its waters emerge from well down in the Lowville, (which alone appears in the plate) and can be seen in the extreme lower left-hand corner. The caving extends many yards upstream and amounts to some 20 feet in hight at the lower end.

Plate 37 gives an interesting illustration, on a small scale, of another feature. The view shows a Lowville platform, surfaced by a resistant layer of somewhat less solubility, and, on the right, the point of emergence of a small, wet weather stream, flowing in a shallow underground channel in the more soluble material underneath. The str am course then curves across the foreground and passes backward and toward the left, its course margined by the projecting edge of the hard layer, which has otherwise been removed from the channel with the exception of the fragment left as a tiny "natural bridge" on the left.

As already pointed out by Ruedemann, in his account of the Lowville inliers in the Leray limestone, very interesting underground features are shown in the Perch river valley about Limerick (Clayton sheet). The rock structure there seems to us to be anticlinal, with the Leray limestone at Limerick marking the site of a sag, and the Lowville inlier, just south, the site of a dome of the anticlinal crest. North of Limerick increased southerly dip transfers the stream from the Lowville to the Leray horizon, south of it diminished south dip transfers the stream back to the Lowville again, the point of transfer being marked by a fall [pl. 23] as is the rule in the streams of the region when passing



Caved-in roof of a small underground stream in Lowville limestone, nearly 3 miles west of Sanford Corners, Theresa quadrangle, looking north. A good position for the camera could not be obtained so that the view does not exhibit the conditions clearly. The issuing stream shows in the lower left-hand corner. H. P. Cushing, photo, 1907

A less soluble, overlying a more soluble layer of Lowville limestone. A small cavern in the latter and covered by the former shows on the right, and a miniature "natural bridge" left in the wearing away of both shows on the left; 3 miles northwest of Sanford Corners. H. P. Cushing, photo, 1907

Perch river emerging from beneath a limestone wall after flowing underground for ¼ mile. Note the sunken appearance of the limestone of the wall. H. P. Cushing, photo, 1908

from the Leray to the Lowville. But when increased south dip brings down the Leray again, at the south end of the inlier, the formation appears as a wall across the valley, and the stream follows the Lowville underground, though its course is marked by a depression in the surface of the Leray above. After flowing underground a short distance the river reappears at the surface, or more strictly the surface comes down to the river level, owing to caving down and removal of the Leray. In plate 38 this emergence of the stream is shown. It quickly passes again underground. The process seems definitely the enlargement of an underground channel by solution until the roof becomes unsupported, sags and caves in where thinnest, with succeeding gradual extension of the caving in process, both up and down stream. About Limerick the Leray limestone forming the stream walls is shown in all stages of disturbance due to this undermining process. The view in plate 23 shows the process in an early stage, and that in plate 39 in a much more advanced stage, the Leray here being in a condition for which Ruedemann's term of "scrambled" is so absolutely applicable, that we can not refrain from utilizing it.

In plate 40, a view of the stream above the falls at Limerick, we seem to have a direct exposition of what the character of the stream is when underground. It seems distinctly a solution, not a corrasion, channel following the joints in beautiful, zigzag fashion. The chief part of the course shown in the view is on a northwest joint, but in the foreground, and also in the background, it is along a set of north joints. It seems to us highly probable that the stream was formerly underground here. Unquestionably the channel is due to solution along, and guided by, the joints. The locality is so suggestive that it is a pity a longer portion of the stream's course can not be photographed. A contrasting view, that of plate 41, shows a limestone surface (the same limestone) corraded and etched by surface solution and wear.

The influence of the low folds in the Paleozoic rocks in causing falls in the streams which more or less directly flow down the dip, has just been noted in the case of the fall at Limerick. The course of the Black river across the south margin of the map furnishes a fine illustration of a stream whose fall is precisely that of the dip, and along which, owing to variations in the amount of dip, repeated falls occur over identically the same rock horizon. The river here has cut a shallow valley in rock, in postglacial times, and the chief falls in this part of its course are at Felts Mills, Black

River village, Watertown, Brownville and Dexter; and at each locality use is made of the water power. Every one of the falls is over the massive Leray limestone into the Lowville beneath, as well shown in Ulrich's excellent panoramic view of the main fall at Watertown [pl. 42]. There are minor falls of the same type between the chief localities. Below the fall the river flows along in the Lowville until the steepened dip on the western limb of an anticlinal fold carries the overlying Leray limestone down to, and beneath, the water surface, forming the bottom of a shallow, synclinal trough [*see* pl. 28 for such steepened dip at Brownville]. In this the dip flattens, and then becomes low east, bringing the Leray base back to stream level, and giving opportunity for development of the fall as the water passes on to the less resistant Lowville beneath, the fall so begun slowly cutting back up stream with gradual increase in hight. Down stream the river remains on the Lowville under the general low anticlinal arch, until the drop of its western limb again puts the Leray limestone beneath the river level, with repetition of the previous conditions and another fall where the limestone comes back again. Because of the westerly dip the western limb of the anticlines is steeper than the eastern, and the river cuts the bottom of each syncline at substantially the same horizon. The diagram [fig. 12] will illustrate the conditions, which are somewhat exceptional, better than can be done verbally.

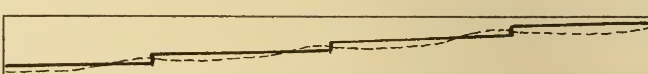


Fig. 12 Diagram illustrating the rock structure which gives rise to the successive falls in the Black river, the heavy line representing the river bed with three falls, and the sinuous dotted line the base of the Leray limestone, showing how, due to the folding each fall is over the same rock horizon as its predecessor. Dips and fall of river much exaggerated

PLEISTOCENE GEOLOGY[1]

History

A brief outline of the Pleistocene history and its relation to the earlier time is given on pages 23 and 24.

At least three distinct episodes are recognized in the recent geologic history of our region. These are (1) burial under the ice sheet, (2) burial under standing waters, (3) renewal of the exposure to the atmosphere.

Glaciation. The glacial theory has long since passed into the category of accepted fact. That our area has been subjected to

[1] By H. L. Fairchild.

Leray limestone overlying Lowville, banks of Perch river at Limerick, near the point at which plate 21 was taken. Shows the Leray breaking up and working down the bank, owing largely to solution of the Lowville beneath. H. P. Cushing, photo, 1908

Plate 40

Perch river above the falls at Limerick, Clayton quadrangle [*see* pl. 23]. The rock is Leray limestone and the stream course here follows enlarged joint cracks, first one set and then another. The enlargement seems wholly owing to solution and likely was formerly an underground channel. Looking northwest and upstream. E. O. Ulrich, photo, 1908

Stream erosion of Leray limestone, west edge of Watertown; north bank of Black river. Looking south. H. L. Fairchild, photo, 1908

Plate 42

Fall in the Black river at Watertown; river falling over the lower bed of the Leray limestone into the Lowville beneath. E. O. Ulrich, photo, 1908

the rubbing and grinding action of a continental ice sheet has long been recognized, and now it seems almost certain that instead of only one there have been several ice invasions of the territory. Students of glaciation find evidences of multiple glaciation in the Mississippi basin, in Canada, in New England and in Pennsylvania. It seems impossible that New York should have escaped occupation by ice sheets that buried surrounding territory. In the Mississippi basin the glacial epochs have been named as follows, in order of time: Jerseyan, Kansan, Illinoian, Iowan, early Wisconsin and later Wisconsin. While there is some doubt as to the validity of the Iowan yet the multiplicity of the glacial invasions seems to be a fact. The intervals between the glacial stages, the interglacial epochs, are believed to have been long periods of temperate climate. It seems possible that our present time of release from glacial conditions may be only a warm interval between the latest ice invasion and another invasion to come in the near (geologically) future.

This matter of multiplicity of ice invasions is here emphasized for the reason that the glacial features of our district seem to require for satisfactory explanation the work of more than a single ice sheet. The glacial phenomena will be described in proper order.

Submergence. *Lake Iroquois.* As the latest glacier waned and the front receded and moved northward the ice was replaced by a body of water, the glacial lake Iroquois. This great lake, held in the Ontario basin by the ice barrier blocking the St Lawrence valley, and with its outlet at Rome to the Mohawk-Hudson, laved the receding ice front continuously over all the area described in this paper. An important effect of this condition, which the reader should hold in mind, is that all the materials left by the waning ice were laid down beneath the Iroquois waters, and are consequently more or less modified by the water action.

The present altitude of the Iroquois beach east of Watertown is 733 feet. The only point on the entire area covered in this paper which is sufficiently elevated to reach the Iroquois plane is the extreme southeast corner of the area, as shown at the bottom of the Theresa sheet, [pl. 44]. Here the nose of the Rutland promontory brings the 800 foot contour on the map and the Iroquois shore line is a steep cliff on the limestone scarp. On account of the postglacial uplift and northward tilting of the region the Iroquois plane, and all later water planes, rise to the north. On the parallel of Redwood it is estimated that the Iroquois water surface was about 800 feet, and at Chippewa Bay toward 900 feet. The depth of water over

the plain at Watertown was 200–250 feet, at Lafargeville about 350 feet, and over the plains at Chippewa Bay about 550 feet.

Eventually the ice barrier weakened in the St Lawrence valley and the Iroquois waters found a new outlet north of the Adirondacks which was lower (at that time) than the old outlet south of the Adirondacks by the Mohawk valley. One point of escape was the "Covey Hill gulf," precisely on the international boundary between New York and Canada, about 4 miles northeast of Clinton Mills.[1] The Covey gulf is a great V-shaped gorge in hard Potsdam sandstone, leading north of east, and it carried the waters of the second stage of Iroquois, or the Hypoiroquois, over to some lower level in the Champlain basin. From aneroid measurements it is estimated that the altitude of the head of the gulf is about 850 feet, or perhaps somewhat higher, but when the gulf was made the district was at least 460 feet lower than it is today, and must have been lower than the Rome outlet, which is now 430 feet. It appears that the Covey gulf outlet was not much lower that the Rome outlet, perhaps 50 feet and possibly 100 feet. It might seem as if the Covey gulf outlet represented sufficient length of time for the lake waters at that level to produce recognizable features along favorable stretches of the shore line, and such may yet be found. Dr Gilbert has suggested that possibly the Covey gulf was chiefly cut by a more ancient glacial outflow and that the Hypoiroquois may have done little work beyond clearing out the old gorge.

As the ice front melted back this second stage of the glacial waters of the Ontario basin found yet lower escape along the north side of Covey hill, between the ice wall and the rock slope. This third phase of the Iroquois waters must have been short-lived, with rapidly falling levels, the river flow only terracing the sandstone slope. It is thought that the final effect of this down-draining of the glacial waters was to bring them into confluence with the oceanic waters which then occupied the Champlain basin and are called the Champlain (Woodworth's Hochelagan) sea. The supposed extension of the sea-level waters into the Ontario basin is known as Gilbert gulf.[2]

Gilbert gulf. If our present conception of the history is correct the sea-level waters covered nearly all the territory comprised in our five quadrangles. On the north slope of Covey hill the Champlain beaches have an altitude of at least 460 feet, which is the measure of the amount of land uplift in

[1] For description and illustrations of this outlet see paper by J. B. Woodworth, Ancient Water Levels. N. Y. State Mus. Bul. 84. Ebenezer Emmons and G. K. Gilbert had noted the feature.

[2] Gilbert Gulf (Marine Waters in Ontario Basin). Fairchild, H. L. Geol. Soc. Am. Bul. 17:712-18.

that district since the ice left that locality. The Gilbert plane declines to the south and southwest and on the south border of our area the beaches are 390 feet [pl. 45]. North of Lafargeville [pl. 46] strong beaches lie at 440 feet, and 2 miles southeast of Redwood a bar is found at 450 feet altitude [pl. 47].

It has not seemed practicable to make maps for this writing to show all the Gilbert shore lines of the area, but the strongest shore features are indicated on the maps, plates 45–47. These are wave-built bars and spits and wave-washed limestones. Some of these features are shown in the halftones, plates 48–53. The southeast portion of our area, being the southeast diagonal half of the Theresa sheet, was mostly above the Gilbert waters. The submerged parts are such as lie below 400 feet at the south edge of the sheet and below 440 feet at the north edge. It will be seen that this is the low ground north and northeast of Brownville, the valley of Perch river, the low ground about Theresa and the valley of Indian river. All the rest of the region was under the full Gilbert level except the three limestone hills northwest of Dexter; the limestone plateau between Stone Mills, Depauville and Lafargeville; the limestone plateaus north of Depauville; the boulder-kame hill 2 miles north of St Lawrence corners, known as the "Hogback"; and the group of boulder-moraine hills north of Lafargeville; one being cut by the edge of the Theresa sheet. These areas which received wave action so as to leave beach records are mostly shown in the plates 45, 46 and 48.

While all surfaces between the highest Iroquois and the Gilbert planes have been wave-swept by the subsiding waters, and many patches of bared rocks are found at various levels, no beach phenomena have been noted between the two planes. All the high level shoreline features in our district are confidently referred to the sea-level waters.[1]

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[1] Since this paper has been in type Prof. George H. Chadwick discovered heavy beaches and deltas of Lake Iroquois in St Lawrence county, and also extensive deltas inferior to the Iroquois plane and of uncertain relationship. In August 1910 we examined these features and carried the study northeastward into Canada.

The Iroquois plane is now definitely known at several points, the farthest east being at Chateaugay with altitude 975 feet. On the international boundary at Covey hill the full-hight plane is not much above 1000 feet. The head of Covey gulf, the outlet of the lower or Second Iroquois, is about 980 feet.

A recent survey on the Canadian side of the boundary gives us precise altitudes for the sea-level beaches (Gilbert gulf), which have at Covey Hill post office a hight of a least 523 feet.

These altitudes are entirely consistent with the figures and facts relating to the Iroquois and Gilbert gulf water planes given in this report.

From the Iroquois to the Gilbert levels the waters fell with comparative rapidity by the removal of the ice dam. The apparent lowering of the Gilbert waters was on the contrary by the very slow uplifting of the land out of the sea-level waters. This rising of the land must have been so slow as to give opportunity to the waves at all minor levels to produce shore line phenomena, and many such are found. However, such proofs of the presence of standing waters are missing over long stretches of even the summit plane, which emphasizes the well recognized fact that absence of clear wave work does not necessarily prove the absence of standing waters.

But while beach phenomena may be lacking or weak over wide stretches we find other evidences of the waters. Either by the lowering of the Iroquois waters over the higher ground or by the lifting of the lower ground through the Gilbert waters all the land surfaces have been brought into the zone of wave action and subjected to erosion or deposition by the agitated waters. In consequence the steep slopes, the projecting rock masses, tables and knobs, have been more or less cleared of their drift and specially of the finer material, which has been shifted to lower levels. The broader plateaus and plains have been smoothed and the lower grounds, valleys, basins and hollows, have been more or less filled or silted with the detritus, sand or clay, washed from the higher ground. This action explains two striking characters of the region, the areas of bare rocks and the silt-filled basins, which will be discussed later.

Conclusive proof that the lower waters were confluent with the sea would be the finding of marine fossils. Such have not yet been found in the Ontario basin, though they are abundant in the Champlain and St Lawrence valleys, and marine shells have been found as far west as Ogdensburg.

Atmospheric erosion. The whole region, above the Ontario level, has long been subjected to a renewal of the atmospheric agencies. The length of time is unknown, but is not equal for all the area. For the lower plains, near the present lake, the time must somewhat exceed the life of Ontario; while for the higher ground, above the Gilbert levels, the time must cover not only the life of Ontario but also that of Gilbert gulf. If we estimate the life of each of these water bodies as 10,000 years it may give some fair conception of the duration in years. For lands above the reach of Lake Iroquois its length of life must be added to the time of exposure, at least another 10,000 years. It is likely that these figures are too small rather than too large.

Physiography

Glacial diversion of the Black river. The history of the Black river is not only the most interesting problem connected with the evolution of the physiography of the region but specially important as it may supply the key to Tertiary drainage of the entire area.

In only the middle portion of its course has the present Black river any pronounced valley. The headwaters and upper section, about 30 miles long, lie on the crystallines of the southwest slope of the Adirondacks, with no conspicuous valley. The lower section, below Carthage, has only a shallow postglacial channel. The great valley begins at about Forestport and extends northwest to Carthage, a distance of more than 40 miles, and steadily deepens and widens northward. At Glenfield or Lowville, near the middle part of the valley, the altitude of the river is 740 feet, while the great ridge on the west, separating this valley from the Ontario, rises to 2000 feet, and the breadth of the valley is at least 10 miles on the 1300 foot contour.

Former writers have regarded the Black river as the trunk stream of the early drainage which headed the Ontario valley.[1] It appears to the writer that that view is a mistake and that quite the opposite is the fact, that the Black river was the headwater of the St Lawrence drainage, at least for New York State.

Plate 43 shows the present hydrography of the region and the divide between northward and southward streams of the Ontario-St Lawrence valley. Plates 44 and 47 show portions of the divide on the larger scale of the topographic sheets. On plate 43 the heavy, broken line south of the Black river marks what was the preglacial divide between Ontario and St Lawrence drainage before the Black river was forced by the interference of the ice sheet across the divide. The light, continuous line indicates the present and shifted divide. It is apparent that below Great Bend the river has peculiar and anomalous relationship, and that the divide leading east up the Adirondacks slope is newly established.

In discussion of this problem the theoretic evolution of the drainage will be considered first and then the recent history and the present features.

The Black valley was initiated and developed, at least as early as the Tertiary uplift, along the contact or overlap of the Ordovicic sedimentaries on the ancient crystallines. The west wall of the

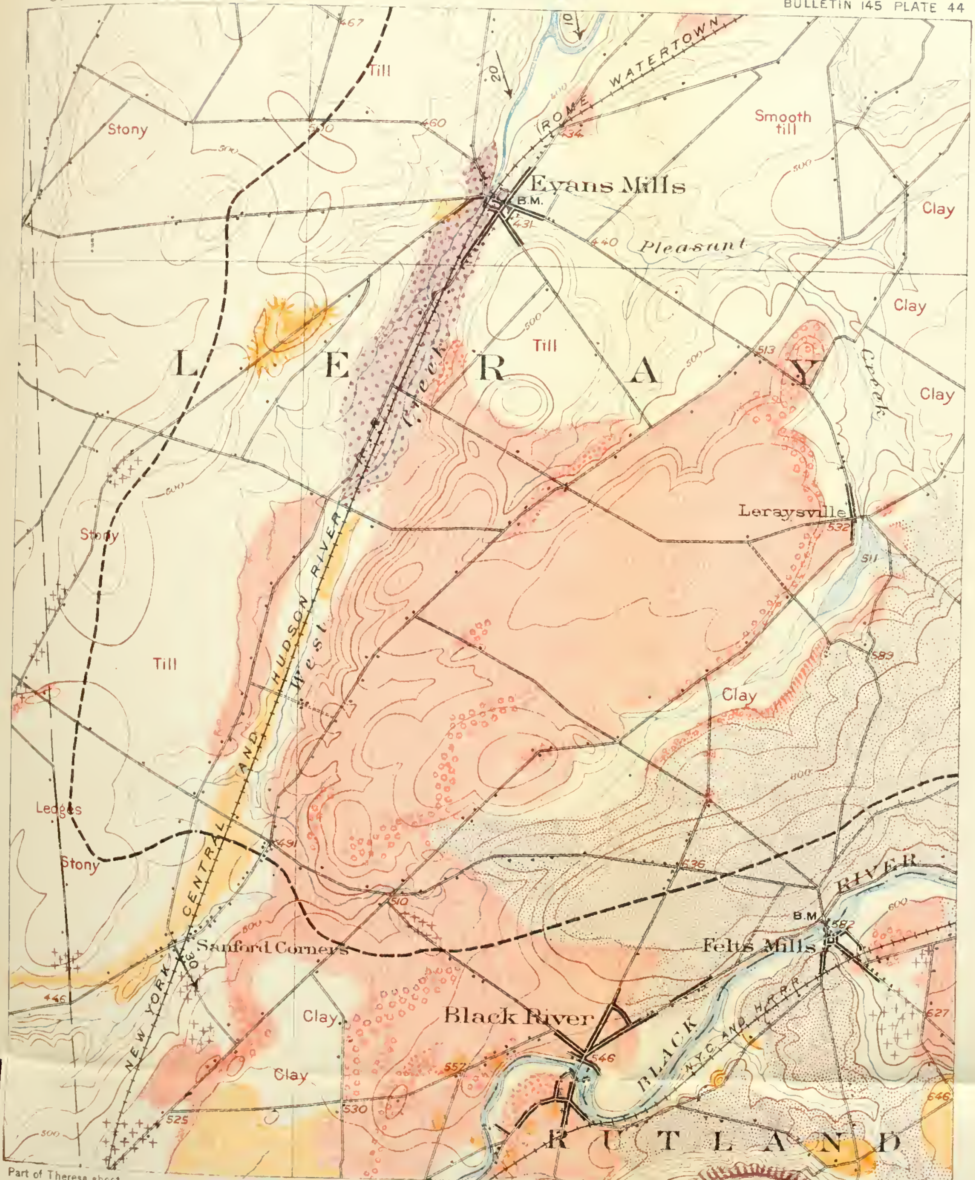
[1] Specially the paper by A. W. G. Wilson, Trent River System and the St Lawrence Outlet. Geol. Soc. Am. Bul. 15:211-42. Pages 236-38 refer to our district. With the entire article excepting the point of the Black river relationship we are in hearty accord.

great valley shows all the strata from the Pamelia to the Oswego sandstone. The east wall of Precambric rocks is deeply buried under sand plains or delta deposits accumulated in glacial waters.[1] The axis of the deepening and north leading valley migrated westward, down the slope of the basal crystallines and against the outcrop of the sediments.

The great ridge dividing the Black and Ontario valleys now terminates abruptly in the Rutland promontory with a limestone scarp about 400 feet high. The point of this promontory is shown on the lower edge of plate 44, south of Felts Mills and Black River villages. A glance at the Watertown sheet will show how the river below Felts Mills clings to the foot of the scarp. A moment's thought will make it evident that these thick limestones did not originally end here, but must have extended far north, overlying the district toward the St Lawrence. It seems perfectly evident that the stratigraphic relations and the erosional conditions which produced the Black valley above Carthage must once have extended much farther northward, and the Tertiary river probably had its course northward along what is now the east slope of the St Lawrence valley, in continuation of the Forestport-Carthage valley. The problem is therefore narrowed to the question of the time of the removal of the Trenton limestones north of the Rutland promontory, and the date of the diversion of the river from its northward into its westward course.

A singular physiographic feature of the region is the northward or rather northeastward direction of all the heavy streams north of the Black river. These all flow along parallel with the St Lawrence, and in some sections at even lower levels. In normal stream development the tributaries should flow toward the trunk stream. The Indian, Oswegatchie, Grass, Raquette and St Regis are more or less independent of the St Lawrence and are not normal tributaries. Their courses have probably been modified, straightened and their parallelism emphasized by repeated glaciation, but the latest ice erosion has certainly been insufficient to produce such channels. Their direction is in precise opposition to the glacial effect and also in opposition to the postglacial uplift of the region. It is in harmony with and in continuation of the Black valley, curving eastward around the uplifted mass of the Adirondacks. It seems altogether likely that these stream courses were developed by north leading drainage having practically the same stratigraphic

[1] See a paper by the writer, Glacial Waters of the Black and Mohawk Valleys. N. Y. State Mus. Bul. *In press.*



LEGEND

Marginal Drift, Moraine

Ordinary moraine

Very stony

Boulder ridges

Marginal Drift, Kame

Sand areas

Sand knolls

Lake Iroquois Features

Cliff shoreline

Delta sandplain

Bared rock

Gilbert Gulf Features

Sandplain; delta (?)

Glacial Striae

Numerals indicate degrees from meridian

Drainage Divide

Between northeast and southwest flow.

PLEISTOCENE FEATURES: BLACK RIVER DISTRICT

relation as that which initiated the Black valley. The only features which are not in harmony with the above theory are the southward course of a section of the Indian river, above Evans Mills, and of the Oswegatchie above Oxbow. These are probably due to glacial diversion, similar to that of the Black below Great Bend, but for better knowledge we must await the topographic sheets.

Professor Cushing suggests that north from Felts Mills the preglacial divide might have swung west from the present course, passing south of Perch lake, through Depauville and south of St Lawrence corners. The wider valley of the Chaumont north of Depauville and the northward course of French creek favor this view. It is quite possible that Prewisconsin glacial erosion has caused a northward migration of the portion of the divide that was transverse to the ice flow, but the latest ice work seems to have been too weak. We may not appeal to forced stream flow during the last ice recession, as the region was then buried under Iroquois waters. The northward uptilting of the area tends of course to divert sluggish drainage into southward flow, but alone this could not be a very effective factor.

Passing now to certain specific data and features connected with very recent history, the reader should note again the intimate relation and parallelism of Black river to its northward flowing neighbors [pl. 43], after which a glance at plate 44 will show the cause of the separation and the character of the barrier. At Great Bend and Felts Mills the river has cut into the south side of its own delta, that was built in Lake Iroquois. Along much of that stretch rock is seen in the bed of the river, beneath the steep wall of the delta deposits. North of the delta the ground is 100 feet or more lower than the river, and all draining northward. At Felts Mills the river has an altitude of 580 feet, while only 1½ miles north, and simply across the delta divide, is Pleasant creek, a tributary of Indian river, at only 520 feet altitude. The fall from Black river to Indian river by Pleasant creek is 200 feet in about 6 miles. Further up stream, at Great Bend the river has a large meander in the delta and the facility for northward flow may be even better than at Felts Mills, but the topographic survey has not covered the district.

The suggestion is natural that possibly a rock barrier is buried under the delta, which would be an effective barrier to north escape of the river if the delta were removed. Fortunately we have specific data. Mr F. A. Hinds, the well known hydraulic engineer of Watertown, has pointed out the important fact that the drainage

of the great sponge of sand plain, on which is located the military camp, is not into the Black river but north into the Indian river.[1] Along the north side of the sand plain huge springs gush out along the contact with the impervious drift, while such are entirely wanting on the Black river side. It is certain, therefore, that if the delta at Felts Mills and Black River were not there the river would plunge northward. It is equally certain that before the ice invasion, and the deposition of the delta and moraine barrier, the river did flow northward. The only condition which could produce southward flow would be a northward uplift 20 or 30 feet per mile greater than we have today, which is extremely unlikely for this district. As long as any of the St Lawrence valley drainage passed north the Black river went with it.

The westward course of the Black river from Great Bend is due to glacial diversion. The river is on rock and with no proper valley. It is in a postglacial channel. Moreover, there is no south leading valley in the Watertown district sufficient for a large river. If there were the Black would be in it today as there is no heavy drift barrier to block drainage in the district south of Watertown.

The later history is quite clear. During not only the advance and retreat of the latest ice sheet but probably that of earlier ice sheets the Black valley high-level waters were forced westward and southward around the Rutland promontory. High on the slopes at Copen-

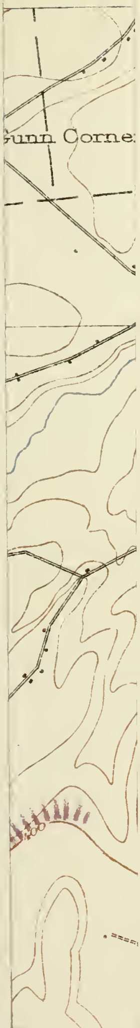
[1] Extracted from report of Frank A. Hinds to the Water Board of the City of Watertown, June 29, 1908.

. . . the entire country slopes toward the north and west and away from the bank of the river which is the highest part.

The Pine Plains is a sheet of very clean sand from 50 to 75 feet thick and covering an area of from 25 to 40 square miles. The sand is so porous that all the rainfall sinks directly into it and forms a natural reservoir at the bottom. This ground water has a slow movement in the direction of the slope but does not become exhausted during the dry season as the constant character of the springs at its edge proves.

While the water of the river opposite the (U. S. military) camp is 100 feet below the surface of the plains, there is an impervious bed of clay and rock underlying the sand which is from 30 to 50 feet above the river. This clay may be seen in many places along the bank, though in others the sand has run down and covered it over. Five miles to the west the sand plateau stops and the clay substratum continues as the surface soil of the country; but here it is 100 feet lower than where it commences at the river brink under the camp.

This northwesterly slope of the subsoil determines the direction or flow of the underground water and accounts for the fact that there are but few and comparatively small springs flowing into the Black river from under the plains, while those along the western border of the sand are more copious and gather into several creeks or brooks of noticeable magnitude which flow westerly into the Indian river. The few springs along the Black river bank are where the underground water spills over the easterly upper edge of the clay stratum, but they are comparatively few and small . . . the water which emanates from under the Pine Plains does not get into the Black river to any extent worthy of attention.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PLEISTOCENE FEATURES: CHAUMONT-BROWNVILLE DISTRICT

H. L. Fairchild, 1909.

hagen and Champion are the glacial channels [*see* footnote p. 142]. The Rutland Hollow is a capacious valley cut obliquely across the nose of the promontory, parallel in direction with both higher and lower glacial channels of Black valley outflow, and was undoubtedly given its form and dimensions by glacial drainage. When the Black valley waters were lowered into Lake Iroquois the Black river built its delta in the lake northwest of Carthage, partly banked against heavy moraine. When Lake Iroquois was lowered into Gilbert gulf the Black river found its ancient course obstructed by the delta and moraine deposits and was compelled to follow around the rock promontory in the path of the stronger shore currents in the lake. West of Watertown the river dropped its detritus in the sea-level waters (Gilbert gulf), and when these waters were lowered by the land uplift the river pursued its chance course over the rock toward the retreating water body.

To epitomize: It seems certain that the earliest drainage which we can locate must have been along the weak zone of the overlap of the sedimentary rocks on the Precambric, in north and northeast continuation of the Black valley. Preceding the latest ice invasion the Black river probably flowed north. Just what may have occurred during the Tertiary uplift and the earlier Pleistocene we do not know. It is possible that there are unsuspected elements in that long history, but there is no discovered reason for any preglacial southward drainage across the divide as mapped in plate 43. The really uncertain factor is the glaciation earlier than the Wisconsin epoch. The writer is inclined to credit to glaciation earlier than the Wisconsin considerable influence in producing the parallelism of the rock forms and the drainage lines along the St Lawrence depression; and the bluntness and roundness of the Rutland promontory; and the cutting of the Rutland Hollow.

Topographic features. *Parallelism.* The topographic elements of the area have a conspicuous parallelism, about northeast and southwest, in accordance with the St Lawrence valley and river. On the Clayton and Theresa sheets this shows clearly in the stream and valley courses and in the trend of the plateaus and rock hills. On the Alexandria and Grindstone sheets the parallelism appears in the elongation of the rock knobs and the form of the lakes and the islands in the river. This character prevails down the valley far beyond our district, as shown by the river courses which instead of flowing directly to the St Lawrence follow along in parallel courses [pl. 43].

The genesis of this prevailing orientation probably involves factors which cover the entire geologic history of the region. In an earlier chapter Professor Cushing has shown that during the time of the earliest sedimentation in the region there was alternately a tipping to the northeast and the southwest, the fulcrum of motion lying across our district, initiating what is called the Frontenac axis [p. 95]. The broad depression of the valley is thought to be partly the result of sagging, accompanied by jointing, one main trend of joints having fair agreement with the trend of the valley. Cushing also shows that some slight folding occurred in Paleozoic time and stronger folding in Precambric time which probably had some directive influence on the drainage [p. 108–115].

The larger existing features and general stream directions were developed during Tertiary time under subatmospheric erosion. During Pleistocene time the St Lawrence valley, being closely in line with the spreading flow of the ice sheet over the region, served as a trough for the advancing and the waning ice lobes. We do not know the number of ice invasions but it seems quite certain that the latest, or Wisconsin, ice sheet was preceded by others of probably greater effectiveness in erosion. The striking parallelism of the minor features of the topography is probably due in some degree to repeated glaciation, the alternation of ice flow of the glacial epochs and the stream erosion of the interglacial epochs mutually assisting or guiding each other.

Dominant types. The topographic features in the sedimentary rocks are naturally an expression largely of the stratigraphic characters. This has already been discussed in a former chapter by Cushing [p. 121–136]. In the present connection we have to consider the topography in its relation to the glacial and glacioaqueous history.

Leaving out of account for the present the localized and scanty moraine deposits, we may distinguish two dominant types of the surface relief in the area; (1) the rounded rock hills or knobs of rather striking relief in the northern part of the area, in the district of Potsdam and Precambric rocks, and (2) the broad level stretches which characterize the southern half of the area, where the rocks are well stratified.

Rock knobs. In the northern part of the area, covered by the Grindstone and Alexandria sheets and the northeast part of the Theresa sheet, the crystalline rocks and the lower Potsdam appear commonly in the form of knobs or bosses, singly or in clusters and chains, as illustrated in plates 6 and 7. Cushing has shown [p. 54]


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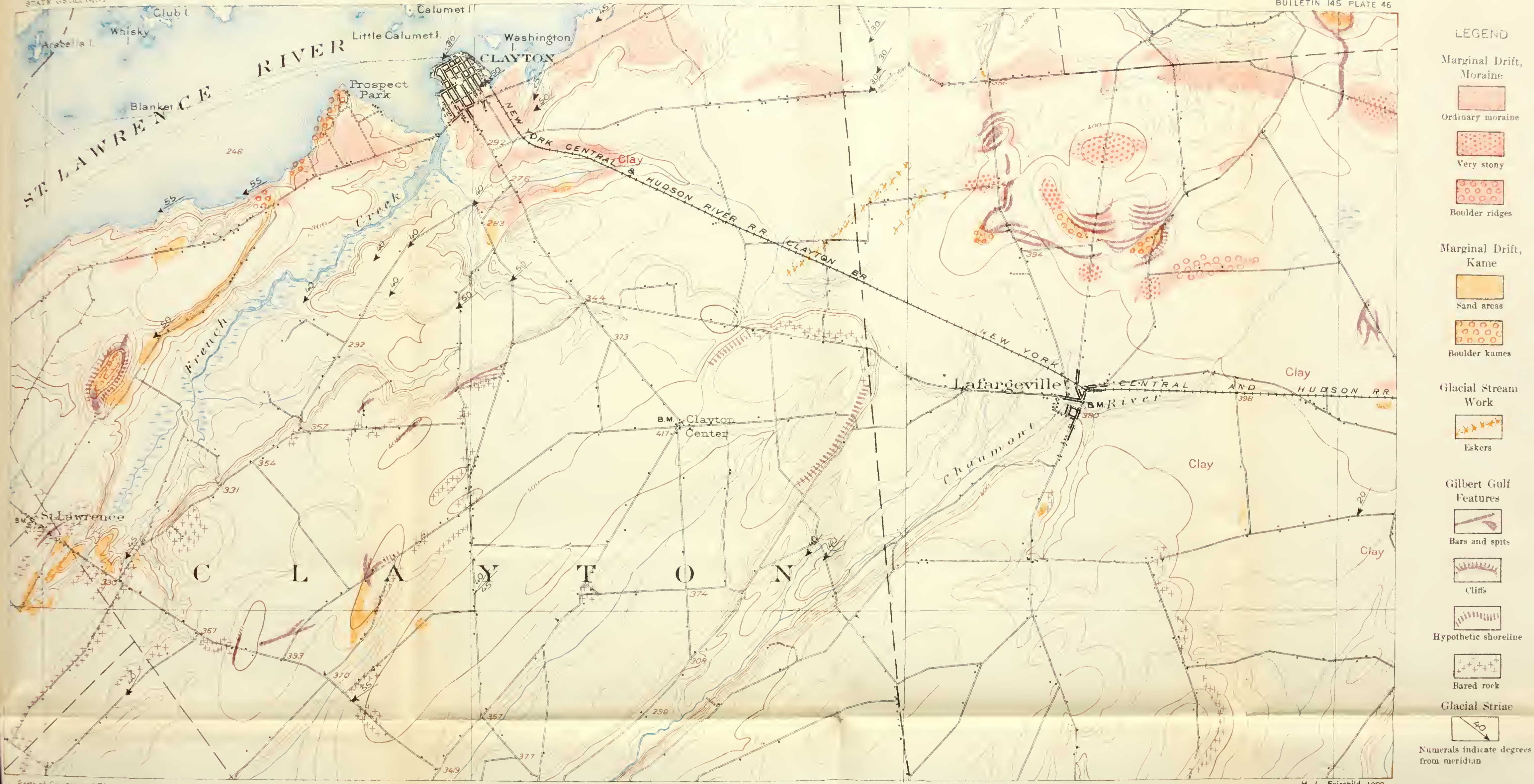
BULLETIN 145 PLATE 46



Parts of Clayton and Theresa sheets

H. L. Fairchild, 1909.

PLEISTOCENE FEATURES: CLAYTON-LAFARGEVILLE DISTRICT

that the knobby surface of the crystallines is the immensely ancient erosion surface of the Precambric land area, which had been buried under Potsdam sediments and only recently uncovered. Ice erosion seems to have had very little influence in shaping the surface, merely rounding and smoothing the knobs.

The major axes of the knobs are roughly parallel with the valley and the ice movement, but the relation to the latter is mostly casual and not genetic. The struck or northwest side commonly shows more erosion, but frequently the difference is not evident. As a rule the crystallines have not retained their striae and polish as well as the Potsdam sandstones.

Plains of erosion. The broad plains, either rock or rock floored, are regarded as the product of long eras of atmospheric erosion with later glacial planing and a finishing touch of wave smoothing. They are found in districts where the sedimentary rocks are persistent in considerable thickness so as to cover the Precambric and the lower and irregular Potsdam. Broad tracts of this class consisting of upper Potsdam occur south of Chippewa Bay and toward Alexandria Bay. Theresa dolomite forms the plain north of Chippewa Bay and covers large areas on the parallel of Plessis and Clayton. South of the parallel of Lafargeville the plains and plateaus are limestones.

The earlier ice sheets seem to have lifted or plucked away the weathered and weak superficial layers of these stratified rocks down to some firm, less jointed and more resistant bed; but the flatness and smoothness of these level stretches is partly due to the latest action, the leveling action of the shallowing waters. The glacial drift is commonly thin on these plains and patches of bare rock are very frequent, sometimes acres in extent, specially on the Potsdam. A good example is seen at Plessis, which village was formerly called "Flat Rock." On the highways rock frequently occurs in unexpected manner and often forms the wagon track for considerable distance. Although glacial polish and striae occur frequently on the Potsdam the majority of exposures have either lost their smoothness or were never severely rubbed. On the other strata glaciated surfaces are not common.

These plains have been trenched by stream erosion and many of the valley walls are yet steep, those of Chaumont river for example. The differential erosion of the several strata has produced scarps or benches about the margins of the higher plains which are frequently striking features of the landscapes and sometimes are persistent for long distances. These have been described in a former

chapter in connection with the stratigraphy [p. 129]. The valley and scarp topography is certainly older, at least in great part, than the latest glaciation.

Plains of deposition. Flat stretches of detrital deposits occupy the valleys and basins in the northern part of our area and the lowlands in the southern part. They are broadly developed over the southwestern part of the area, covering nearly all of the Cape Vincent sheet and a large part of the inferior levels of the Clayton sheet. Doubtless the more elevated of these detrital plains have rock floors, those about Lafargeville and Clayton for instance, but the rock is masked; while the valley and basin fillings are deep clay.

These plains are chiefly clay, though sometimes sandy silt and occasionally sand. They represent the distributing and leveling work of standing waters, Lake Iroquois and Gilbert gulf, and are described with reference to origin in a later chapter, page 156. The best example of the sand plains may be seen 3 miles southwest of Theresa, crossed by the Clayton branch of the New York Central Railroad between Theresa Junction and Strough. Beyond this, both east and west of Lafargeville, the plains are clay. From the trains on the Cape Vincent branch of the railroad the clay plains may be seen spread far and wide, as flat as a prairie, all the way from Limerick to Cape Vincent, with a few interruptions of rock or of till ridges.

The more extensive, upland clay plains shade off into till, while some of the valley clays are conspicuously pitted, as if deposited over ice [p. 158, pl. 47].

Lake basins. Perhaps the most puzzling of the physiographic features are the basins or basinlike valleys with steep rock walls. These are more striking in the district of Potsdam and Precambric rocks of the Alexandria quadrangle, where they hold an interesting group of lakes, the only lakes in our area, excepting Hyde and Perch lakes on the Theresa quadrangle. The five lakes of our area, near Redwood, shown in plate 47, are only the western members of a large group. Some basins without lakes and some steep-walled valleys in limestones on the Theresa and Clayton sheets are probably of similar genesis.

Two facts in connection with these basins are specially to be noted, the steep, scarplike rock walls and the very small amount of glacial drift. These features seem abnormal in a district that has been subjected to probably repeated glaciation. While these depressions are mostly oriented in general harmony with the physiographic alinement of the region, having a northeast-southwest atti-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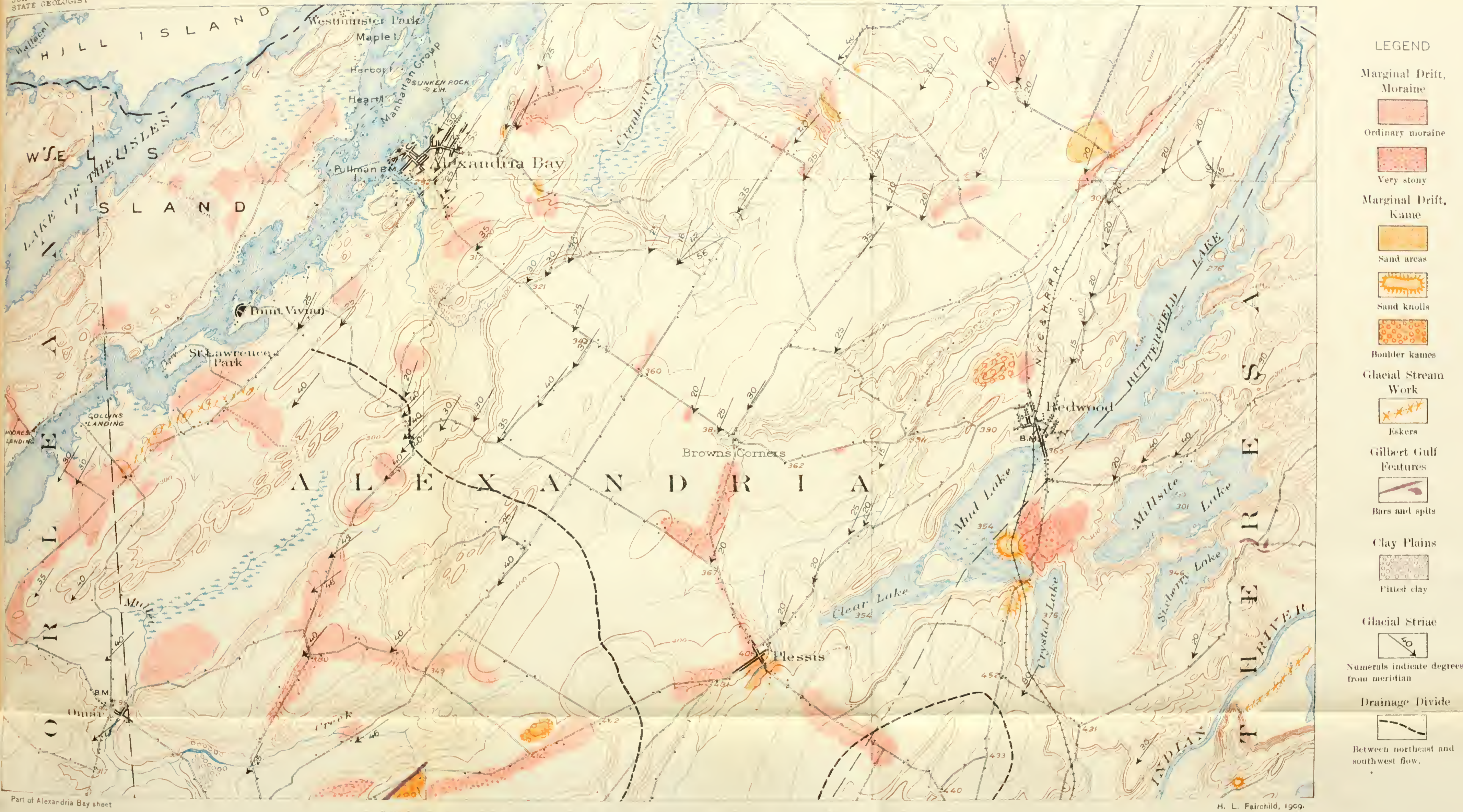

Part of Alexandria Bay sheet

H. L. Fairchild, 1909.

PLEISTOCENE FEATURES: ALEXANDRIA BAY-REDWOOD DISTRICT

tude, which very likely was partly controlled by early glaciation, yet a significant number are transverse. Some basins in the vicinity of Alexandria Bay [pl. 47] and others south of Clayton [pl. 46] do not conform to the prevailing direction, and the basins of the Redwood lakes are so irregular in form as to rule out ice erosion as the dominant agent. It seems certain that these basins, like the scarp borders of the plateaus, are due to atmospheric agencies with only small and indeterminate glacial effects; or that they certainly antedate the latest ice invasion. One would naturally suppose that the scraping ice sheet would have rubbed the transverse valleys full of drift. In some valleys and against some scarps the amount of drift is sufficient to be noticeable, but it only masks the foot of the cliffs. In many relatively deep depressions the drift is scarcely perceptible, though some may be buried under the lake silts which occupy the valley bottoms.

Besides the lack of drift filling is to be noted the absence of preglacial talus accumulations. In places the Potsdam is so freely jointed that the cliffs break down under the frost quite rapidly and heavy block taluses occur which are evidently postglacial; but in most cases there is little or no talus, specially outside the Potsdam rocks. In the case of the limestone walls solution might be sufficient agency to remove the products of weathering, and this might also apply to the Precambric Grenville limestones which form some part of the basins of the Redwood lakes; but such removal can not apply to the almost imperishable Potsdam sandstone. The older fragmental deposits produced by the recession of the cliffs have been removed, most likely by the glacial ice, but without leaving much drift in their place.

The lack of drift in the basins and over the plains clearly implies a lack of drift burden in the latest ice sheet. The cause of this will be discussed later [page 172]. The small abrading power of the ice was probably due to its lack of tools, and evidently it did not have sufficient power of "plucking" or removing blocks in mass to destroy or even seriously cut the steep ledges and scarps which stood across its path.

One suggestion in partial explanation of the somewhat contradictory features, is that stagnant ice occupied the strong depressions over which the upper ice moved by shearing. This would fairly account for the absence of heavy drift in the basins and valleys and the protection of the walls. Another suggestion takes account of the fact that when the latest ice sheet disappeared from this

area the front was faced by about 400 feet of water in the Redwood district. Just what that condition implies in its effects on the ice and the drift is uncertain. We do not know whether the ice melted back as a steep, high front under the dissolving influence of the water, or whether it melted as a thinning sheet, partially protected by its scanty drift, until it was lifted by the water and rafted away.

To epitomize: We conclude that the basins and stronger valleys were excavated by weathering and stream erosion in preglacial or interglacial time, with perhaps some help from early ice erosion; and that the latest ice sheet had little effect beyond clearing out the debris which it found.

Glacial deposits

Introduction. General features. Compared with areas to the southward the area under description has very scanty drift, and has suffered little recent ice erosion. The area did not lie in the zone either of dominant deposition or dominant erosion of the latest ice sheet. Over large portions of the area the rocks are nearly bare, and even in the districts where the drift cover prevails the rock appears frequently and unexpectedly. The amount or depth of drift increases southward but the only heavy moraine lies in the southeast corner of the area [pl. 44].

In considering the character and distribution of the drift it is necessary to emphasize again the fact that during the ice recession the whole area was submerged in the waters of Lake Iroquois, and this was followed by the sea-level waters of Gilbert gulf. The marginal drift was all deposited under subaqueous conditions, and wholly subjected to the distributive action of the shallowing waters.

Over the northern part of the area, where the rock foundation is either Potsdam or Precambric and the land surface irregular, the scanty drift is largely in the depressions, due specially to the work of the shallow waters. Over the southern districts, where the limestones form wide plains or plateaus, the drift is usually a veneer giving the broad stretches flat or gently rolling surfaces. Because of the lack of drift the preglacial valleys are still open, and one of the characters of the region is the valleys and basins with steep rock walls and silt-plain bottoms. The valleys of French creek and Chaumont river are open down to Ontario level; and the Perch lake valley is filled to only 70 feet over Ontario. The open character of these southern valleys is to be only partly explained by the

stream erosion of the clays which constitute the bulk of the drift. The existence of the Redwood lakes in the northern district is an evidence of lack of drift filling.

The normal and common form of drift in regions of glaciation, the stony clay or clayey mixture of rock rubbish known as "till," is widely found but in relatively small amount. The larger drift masses are of three kinds: sandy or "kame" areas; boulder moraines; and pitted clay plains. The extensive plains of water-laid clay are regarded as glacio-aqueous deposits, and are described in a later chapter.

Till. In the northern portion of the area, where the rocks are Potsdam and crystallines and arenaceous materials prevail, the scanty till is sandy and stony. In the southern district where the strata are wholly limestone these give a clayey texture to the drift sheet.

The superficial till is usually incoherent and yellow or yellowish gray in color. In a few places a compact, hard, blue or blue gray till may be found which is regarded as the product of ice action earlier than the Wisconsin. The most massive exposures of the blue till are found south of our area, at Watertown [p. 166].

No drift masses that could be definitely recognized as drumlin have been noted in our territory, though they do occur over the line on the south, north and south of Watertown. Some molding of the till surfaces suggest drumlinizing of the drift, but apparently the till was too scanty to be rubbed into definite drumlin masses.

Moraines. One heavy moraine lies in the southeast corner of our area, between Black River and Evans Mills, mapped in plate 41. This is the only mass of drift of notable size in the limestone district. In the northern part of the area, where the Potsdam sandstone and the knobby crystallines give irregular surface and rather sharp relief, patches of rough and stony drift that may be regarded as morainal are quite frequent; but the only grouping which merits the name of moraine belt lies about Clayton and eastward north of Lafargeville, shown in plate 46. In general it may be said that the peripheral or morainal drift is not collected in well marked lines but is scattering, patchy and indefinite. In districts where the Potsdam prevails at the surface, with scarps and ledges that supplied very coarse material the ice-piled blocks are liable to be confused with the postglacial debris from frost fracturing of the jointed sandstone. As the Gilbert waters have rinsed away the lighter drift from the higher masses it is not easy to readily dis-

tinguish the ice-heaped blocks from the frost fracture piles; the frost work having, of course, also affected the ice deposits.

In some places the morainal character of the drift is clearly expressed by the well known features of irregular surface, mound and basin topography, but over most of the area the morainal element has been discriminated by one or the other of two features; unusually stony patches or kettles. Very stony fields with heaps of boulders and stone fences, specially if containing considerable percentage of nonlocal rock, have been diagnosed as moraine. Discrimination is needed, for in a district of ledges, scarps or cliffs, specially of the quartzitic Potsdam, the ground may be strewn with rubbish from the native rocks which is not strictly morainal, or peripheral to the ice sheet, even if glacial. This criterion of stoniness is often equivocal and in such cases is usually disregarded.

In districts of clayey till the occurrence of kettles or inclosed basins in the drift is interpreted as indicating ice margin deposits, and sometimes they may correlate with stony tracts. Over limestone floors small sinks may simulate kettles, but over the sandstone and crystallines this deception can not occur.

The above description will suggest how difficult if not quite impossible it would be to accurately map the morainal deposits over the entire area, and this is not attempted. The heavier morainic masses are shown in plates 44–47.

Boulder moraines. Plate 47 shows the larger portion of the Black river moraine, which continues southwest to and beyond Watertown. On this map conventional signs indicate lines and ridges of block moraine. Some of these have high relief and are striking features in the landscape. One photograph is given in plate 56. The character of the ridges as bare limestone blocks is partly the result of wave work of the falling waters of Lake Iroquois. The Black river delta built in the lake was banked against the moraine and partly buried its southeastern border. From the trend of these ridges it is apparent that the ice flow constructing them was from the northwest, and that the ice margin was spreading or deploying on the plain.

The great massing of limestone blocks with very few crystallines could hardly have been effected by the earlier ice movement from the northeast or north, as the limestone formations do not extend far in that direction. The change in direction of flow enabled the ice to sweep up the rubbish left on the limestone tract on the northwest, and perhaps the new direction of impact, changing from southwestward to southeastward, gave the ice a more effective grip for

Gilbert Gulf bar south of Pine Grove hill, 4 miles northeast of Lafargeville. Looking north. Altitude about 420 feet. Arrow shows position of camera in plate 49. H. L. Fairchild, photo, 1908

Gilbert Gulf beach, Pine Grove hill, 4 miles northeast of Lafargeville. View facing southeast. Altitude of wave work about 440 feet. Arrow shows position of camera in plate 48. H. L. Fairchild, photo, 1908

Gilbert Gulf shore, north side of Haller hill, 2 miles north (by east) of Lafargeville. Looking east of south from the sixth bar from the summit. Bar basin in foreground. Arrow shows position of camera in plate 51. H. L. Fairchild, photo, 1908

plucking on the limestone ledges; which previously had been attacked from the northward.

The massing or localization of the drift, so unlike anything elsewhere in the southern half of our area, suggests that it was the accumulation produced by a readvance of the ice margin, and was followed by a retreat of the ice front to the latitude of Clayton, where the glaciers made another stand, or readvance, with accumulation of another belt of heavy boulder moraine (or boulder kame) in the Clayton-Lafargeville-Redwood moraine.

Boulder kames. The glacial deposits with sharpest relief and, outside the Black river moraine, the most conspicuous masses are the detached or isolated hills of boulders and cobbles which fall in this class. With little attempt to classify the drift forms these would be called bouldery moraine, but on account of the predominance of water-worn materials in the hills and on their flanks, and their isolation, it is thought best to distinguish them as a form between true moraines and typical kames. They stand out isolated, apart from any line or ridge of moraine, being the most striking hills of their neighborhoods. One known as the "Hogsback" lies 1½ miles northeast of St Lawrence and 4 miles southwest of Clayton and is over 100 feet high. Four smaller but conspicuous conical hills lie in chain, in the line of ice flow, in esker-kame fashion, forming the river front of Prospect Park, west of Clayton. These are shown in plate 46. The same map shows the striking group of cobble hills 2 miles north of Lafargeville, having an east-west distribution and somewhat morainic aspect, which have supplied the materials for the best display of Gilbert bars in the entire area [pl. 49–53]. On the edge of this map and reaching over on the Alexandria sheet [pl. 47] is another prominent hill, called Pine Grove hill, 5 miles northeast of Lafargeville and nearly 4 miles southwest of Plessis. Very heavy cobble bars of Gilbert waters are thrown north and south from this hill, shown in plates 45, 46. A pit for gravel has been dug on the summit of the hill. Yet another hill of this kind is shown on plate 47, ¾ mile northwest of Redwood. There is a chain of similar hills all along the north side of Grindstone island.

From the large amount of rounded or water-transported materials in these hills, their isolation and their form and alinement, it appears that they were built, at least in larger part, by torrential streams. And as all the area was buried under deep waters of Lake Iroquois during the ice waning it would appear that the streams must have been surficial to the ice sheet and have poured

down the steep ice front, into the standing waters. This genetic relationship throws them into the category of water-laid marginal drift, and they are essentially kames. The inclusion of huge angular blocks, apparently contributed directly by the ice, along with the very coarse and largely unassorted materials constituting the bulk of the hills, proves their close contact with the ice front.

The stony composition of these hills has been made more evident by the wave erosion of the waters in which they were buried, the finer materials being swept away from the sloping surfaces. There is a general lack of clayey or adhesive material.

The amassing of such large piles of blocks and boulders, which are only sparsely distributed over adjacent ground, is an interesting illustration of the peculiar mechanical operations of the waning ice sheet, which invites speculation as to the precise genetic processes. The boulder kames hold a considerable percentage of far-traveled fragments, Potsdam and crystallines, which argues against a basal position in the ice of the rock materials, in which case they would be mostly of local derivation. The streams which carried the boulders must have had high gradient, which argues for superglacial flow. This and the unassorted structure of the conical piles argues for a steep frontal slope of the ice at these points. The glacial rivers, like land streams, doubtless had their tributaries, and valleys in the ice, down the walls of which the stones rolled to the streams; so that a river would gather up the rock rubbish from a large area of the ice sheet, and eventually concentrate it in a detrital cone in a notch at the ice margin.

Kames. Deposits of sand and gravel contributed by glacial drainage are well displayed in a number of localities, and several kame areas retain their relief as hills and knolls despite the erosional and leveling action of the standing waters. Indefinite patches of sand are rather frequent and would be much more numerous on our maps if the wide stretches of country between the highways were all examined.

The southernmost and earliest of the kames of the area are in the Black river district, shown on plate 44. Two patches lie south of Felts Mills, close to the limestone scarp. Small patches are west of Black River, and large surfaces north of Sanford Corners and a mile southeast. The sand plain on West creek, south of Evans Mills, marked on the map as correlating with Gilbert waters, may be partly or chiefly kame instead of delta. A kame area of decided relief and glacial character lies 2 miles southwest of Evans Mills.

Gilbert Gulf shore, north side of Haller hill. Looking west from position indicated by arrow in plate 50. Three lower bars and two bar basins in the view. H. L. Fairchild, photo, 1908

Gilbert Gulf shore, east side of Haller hill. Looking southwest from 420 foot bench. Wave work on bouldery drift. H. L. Fairchild, photo, 1908

Gilbert Gulf shore, 3 miles west of Lafargeville. Looking northwest. Showing limit of wave work and removal of drift from the limestone. H. L. Fairchild, photo, 1908

Northward toward Theresa are several extensive sand tracts which are not covered by our maps. East of Strough is a level sand area of 2 or 3 square miles, traversed by the Clayton branch of the New York Central Railroad, which seems to have been mostly leveled by Gilbert waters, but which retains some kame topography along the railroad. Another tract is at Theresa Junction and eastward on both sides of Indian river, and up the river on the west side. Other areas occur: one 2 miles south of Strough, and one a mile south of Theresa. Other tracts, or extension of those noted above, may occur out of sight from the roads.

On plate 46 a series of sand areas are shown extending from St Lawrence northeast toward Clayton, which are related to the Prospect Park boulder kames. Other small sand tracts are marked on this map, and also on plate 47.

Some of these sand areas have not only been modified by the submerging waters but have been worked on by the winds. The dune characters in some cases rather obscures the glacial origin. Some tracts are fine, clean sand, with basins or swampy intervals, like the Theresa Junction area. It would appear that these sands were laid in glacial waters over or among stagnant ice blocks; subsequently modified by the lowering waters; and lastly acted on by the winds.

Eskers. Plates 46 and 47 exhibit several series of kame knolls lying in definite chains in the same direction as the ice movement, some of them blending into true eskers. One stands on the flood plain of Indian river; another close to the St Lawrence river, 4 miles southwest of Alexandria Bay; and two parallel chains 3 miles northwest of Lafargeville. The mapping somewhat overemphasizes the directness and regularity of these esker-kames. The line of sand between the Hogsback and Prospect Park, southwest of Clayton, should probably be regarded as eskerlike, while the four Prospect Park boulder kames, and the Hogsback also, are parts of the chain; that is, they are all deposits made under variable conditions by a single glacial river.

True eskers, gravel ridges of fair continuity and uniformity and lying in line with the ice flow direction, are regarded as deposits in the beds of full loaded glacial streams, either subglacial or superglacial. The true kames are the short lived deltas of the streams, at their debouchment. Only the streams or their deposits which lie in the line of the ice movement could survive. As the ice front recedes the kames may bury or mask the less massive upstream or esker ridges.

Considering their relation to the ice sheet, the kames are essentially morainal in so far as they are peripheral or marginal to the ice sheet. Eskers, specially if of great length, are longitudinal, or parallel to the ice movement, and correspond to drumlins of the ice-laid drift. The esker-kames noted above are not quite typical of either class, and are therefore all the more instructive. In the field these four or five chains are distinct and clean-cut features.

It should be borne in mind that all these detrital deposits were formed when the ice front was bathed by several hundred feet of water of Lake Iroquois. The streams which drained the ice sheet may have flowed in tunnels beneath the ice (subglacial), or in trenches on the ice (superglacial), or rarely within the ice (englacial). To enter the standing water with sufficient force to carry detritus the subglacial streams must have been under considerable head or hydraulic pressure.

The various differences in these water deposits must be sought in the variation of the glacial drainage in its complex relation to the inclosing ice and to the receiving waters, and to the amount and kind of rock debris at different depths in the ice and within reach of the streams.[1]

Glacio-aqueous deposits

Clay plains. The largest in volume and the most extensive of the deposits due to glacial agency, direct or indirect, are the clay plains which were spread by the Iroquois and Gilbert waters. Except where in the Black river district the moraine and delta occupy the ground the prevailing drift of practically all the territory south of the parallel of Lafargeville is this clay; and also large areas of the lower ground north of this line. With exception of some till and thinly till-masked rock ridges all the lower ground of the Cape Vincent sheet and the southwest half of the Clayton sheet is clay. East of Clayton and east and west of Lafargeville the plains are clay, blending into till, or eastward at Strough into sand. Excellent views are afforded of these prairielike plains from the railroads to Clayton and Cape Vincent. In the northern district the clay occupies only the valleys and hollows, where the

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1 The reader who wishes to pursue the study of water-laid drift will find a philosophic discussion by R. D. Salisbury in Glacial Geology of New Jersey. Final Rep't, 5:113-45.

Kames of Central New York are briefly described by the present writer. Jour. Geol. 4:199-59. *See also* Am. Geol. 22:177-80; Am. Ass'n Adv. Sci. Proc. 47:278-81.

On eskers, favoring their superglacial position, *see* an article by W. O. Crosby, Am. Geol. 30:1-39.

Head of rock-walled basin of Sixberry lake, 2½ miles southeast of Redwood. Looking south. H. L. Fairchild, photo, 1908

Plate 55

Lake silts capping hard, blue till. West edge of Watertown, north side of Black river. Cutting for R. W. & O. R. R., Cape Vincent branch. Looking northeast. H. L. Fairchild, photo, 1908

Boulder moraine, 1½ miles west of Black River. Looking northeast, lengthwise of the ridges. Blocks are limestone. H. L. Fairchild, photo, 1908

smooth clay fillings, as meadows or swamps between the rock bluffs or among the rock knobs, make striking contrast [pl. 29].

The clay is evidently the rock flour of the glacial mill, sifted by the standing waters. Its glacial relationship is shown by the fact that in some localities it shades into ordinary clayey till; by its inclusion of boulders and cobbles, probably ice rafted; and by its composition which is decidedly calcareous.

In many exposures the clay rests directly on glaciated rock [pl. 57] with no mass or visible layer of till or stones intervening. In the gullies or storm-wash hollows a few cobbles or boulders are commonly found, derived from the mass of the deposit, but they do not seem perceptibly more common at the base. The bed of the creek where plate 57 was taken was filled with cobbles from the clay ravine. At the top of this section the lamination was destroyed, but the crushing appears to be very localized, and has rarely been noted elsewhere. However, the structure does not often appear, as the exposed clay quickly loses its lamination and forms a rough, crackled skin over the slope, as shown in plate 58. It is only where the clays are freshly exposed that the lamination becomes evident.

In plate 58 the numerous white fragments scattered over the slope are calcareous concretions, discoid or irregular in form. Evidently they represent concentration of the lime that was originally disseminated in the deposit, but the clay still retains enough of the carbonate to effervesce very freely in weak acid. The latter is true of all the clays tested, except in some cases the topping layers, 1 or 2 feet thickness. The lack of carbonate at the surface may be due to postglacial leaching, and perhaps to original lack of carbonate since the latest beds may have been deposited from well washed material, the ice being far removed to the northward.

Some sections do not contain the lime concretions. This is the case with a great exposure 1½ miles east of Clayton where the river has undercut the bank, giving a section 15 to 18 feet high. The lower part is beautifully laminated, the upper part with older exposure showing the characteristic mottled or crackled skin and some small lime particles. The east end of the clay section exhibits some crumpling of the beds. All these clays effervesce freely.

The volume of this clay over the area increases southward, over the limestones, but the total seems excessive in proportion to the scanty drift of other materials. It is possible that the genesis and history of the clay is more complex than would at first appear. Apparently it is all Postwisconsin, for if it were partly the deposit of ice of earlier invasion we should expect to find the deeper and

older beds of somewhat different quality, more or less crushed by overriding of the ice; and tills interbedded between the older and the newer clays. No such features have been seen. In the few sections observed reaching to rock the clay reposes directly on the smoothed rock, and the deposit is similar and homogeneous from bottom upward, and very finely laminated. The cases of crumpling which have been noted are probably explicable by the grounding of icebergs, or perhaps by the thrust of the accumulating weight of clay on weaker borders of the deposit.

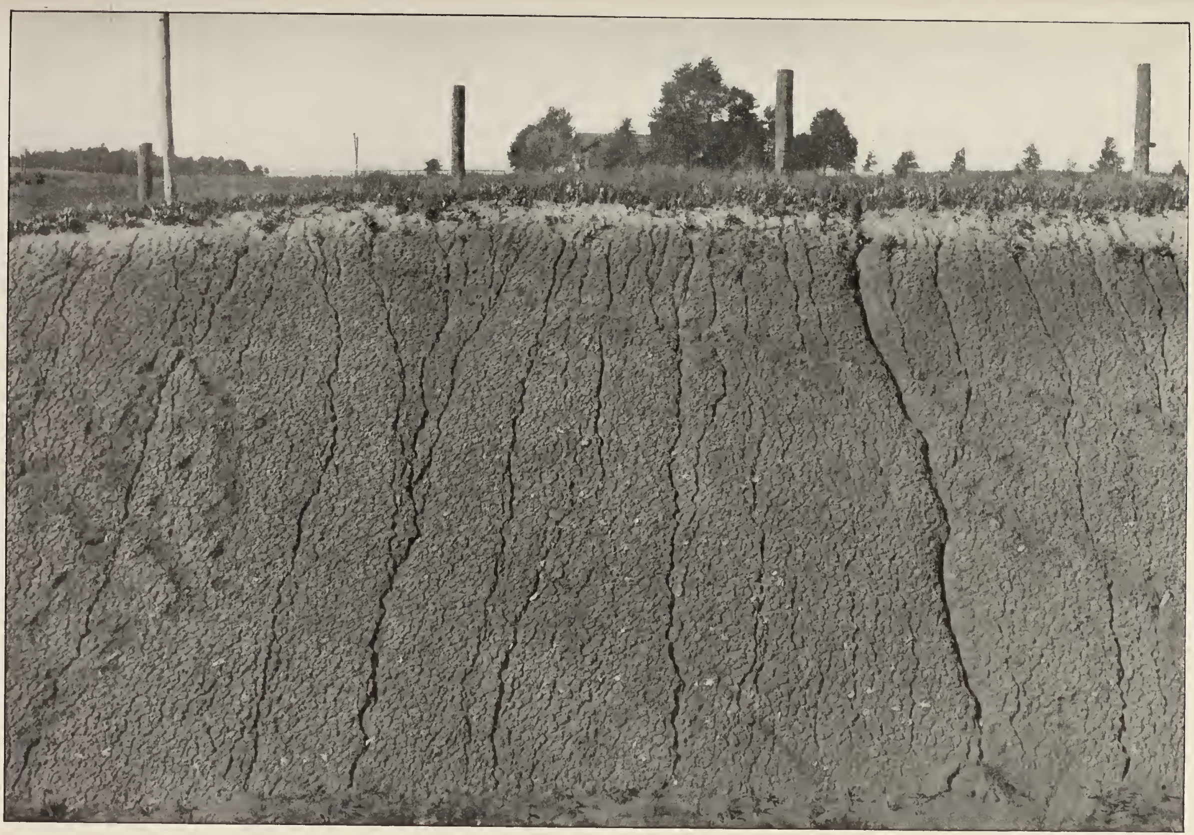
An explanation of the large volume and extent of the clay seems to lie in the consideration of the lake conditions at the front of the waning ice sheet and the mechanical factors working there. In ordinary glacial drift or till the coarse materials remain in mixture with the clay (rock flour) matrix. But the agitated deep water in which all the deposits of our area have been laid down have screened out the coarse from the fine, dropping the coarse near the ice front, and have carried the fine material away by itself farther from the ice front into the more quiet water. It should be understood that the deposits as a whole were accumulated from south to north, following the departing ice front. In other words they grew backward. It is possible that either by lifting or by toppling the breaking ice kept the water agitated and so facilitated its sifting action. The materials contributed by the glacial streams were already under assorting action. Lack of strong, continuous currents, as rivers, or as in tidal seas, prevented the far removal of the silt, and the muddy waters dropped their clay burden over the bottom not far in advance of the ice front. Subsequently the lowering waters scraped the silt which had been dropped on the higher surfaces down into the lower grounds and hollows. As there was no break in the existence of the standing and lowering waters, and consequently no pause in the depositional process, so we find continuity and uniformity in the deposits.

Pitted clays. In the hollows or basins of the Alexandria Bay district [pl. 47] are found deposits of clay which are pitted with basins or kettles. In some instances the silt forms merely mounds and ridges with intervening swales and swamps, a good example being seen 3 miles north of Redwood.

These pitted clay fillings blend on the one hand into till, and on the other into the smooth or merely eroded clay plains. The explanation of their origin seems to be the deposition of the silts over grounded ice or anchored ice blocks. Apparently the ice masses were not melted until the silt deposition was ended.

Silts on glaciated rock, 2 miles southeast of Clayton, by railroad bridge. The rock is Potsdam sandstone; the lower part of the section is sand. The fragments resembling stones are clay masses from the upper beds. Compare plate 58. H. L. Fairchild, photo, 1908

Plate 58



Glacio-lacustrine clay, Dexter. This is the prevailing low-level deposit. An adhering film of the weathered clay hides the lamination. The white particles are lime concretions. Compare plate 57. H. L. Fairchild, photo, 1908

The pitted clays are a link between the ice marginal deposits and the open lake deposits. They might be classed with the morainal or peripheral drift, since they were associated with remnants of the ice front, but the aqueous origin is here regarded as the more important element.

Glacial erosion

General character. The abrasional work of the glacier in this area is more conspicuous in the northern district where the hard Precambric and Potsdam rocks are in high relief and the drift is mostly in the hollows. Over the southern district where horizontal limestones form the floor the ice erosion was probably greater than farther north, but the evidences are more concealed. The origin of the plains, plateaus and mesas, by preglacial weathering, glacial planing and stream trenching, has been discussed in a former chapter [p. 146].

The more vigorous erosion on the limestones is shown by flutings or ribbing, the lighter and later, by striation and polish. The Potsdam and crystalline knobs seem to have been little more than " sandpapered " by the latest glaciation. The broader surfaces of the more horizontal Potsdam shows effective abrasion in spots only. The impression made on the observer is that glaciation of an earlier ice invasion was vigorous but that the latest ice sheet was comparatively ineffective.[1]

Striations. *Occurrence.* The limestones exhibit few striae, as will be inferred from the lack of arrows on the maps of the limestone districts [pl. 44–47]. It is uncertain whether this should be chiefly attributed to the failure of the latest ice to generally abrade the rock surface, due possibly to clayey character of the subglacial drift in this district, or to the obliterative effect of solution and weathering. The limestones are readily attacked by atmospheric waters, as proven by the very numerous areas of solution structures and open joints [p. 133, pl. 26–27, 35]. But in many places the fresh removal of clay or clayey till that would seem to be sufficient protection to the rock reveals unglaciated surface, though usually firm and even, as if a glaciated surface had lost its smoothness. This feature is emphasized by the finding in the same locality surfaces

[1] Unfortunately we have no standard or measure of the intensity of ice abrasion or erosion, or glaciation in general. When a writer says that the drift is scanty or abundant, that erosion has been great or small, he expresses merely his own conception of relative intensity, based on his observational experience. It is apparent that different observers might have different opinions, according to the range of their work and their mental attitude. Moreover, the view of the same student might vary with increasing experience and changing emphasis on the various elements or factors.

recently exposed with perfectly preserved polish. While it is possible that this difference in surface characters may be the effect of differences in present conditions of drainage and solution, though improbable, it seems more likely that we have here another illustration of multiple ice work.

In the Potsdam areas the impression is given of general ice abrasion by the frequent patches of polish and striae; but the unscored surfaces far outnumber the striated. Here, again, we have the uncertainty as to the degree of weathering and destruction of the latest glacial records, because exposed surfaces, apparently of identical quality of rock and equality in exposure exhibit partly highly polished and partly unscratched surfaces. The fact of a general grinding and smoothing of the rock is clear, but quite certainly not by the latest ice sheet.

Direction [*see* pl. 44–47]. Near the St Lawrence the average direction of striae is about parallel with the river. Leaving out the extreme and aberrant marks they may be generalized as follows: at Chippewa Bay, s. 25° w.; Alexandria Bay, s. 25–40° w.; Clayton, s. 40–50° w.; eastward from the river and from the axis of the valley the striae are more variable and swing more southerly. About Redwood some striae are s. 40° w., probably representing the stronger flow of the deeper ice, but a great number range within s. 10–20° w. About Theresa the greater number lie within s. 10° w. and s. 10° e. East of Chaumont the striae are s. 35° e.; at Evans Mills, 10–20° east of south and at Sanfords Corners, 30° east of south. The Leraysville moraine [pl. 44] clearly shows the southeasterly push of the latest ice in the district. This easterly swing of the ice in the eastern part of our area was due to the well known spreading or radial flow of a lobation in the ice front. As the ice sheet waned the last portion resting over the area was a broad lobe occupying the St Lawrence depression and having spreading flow toward the east side of the valley. Along the east side of our maps the most westward striae represent the general direction of the maximum flow while the eastward striae are later scratches by the ice margin.

Curved scorings. A remarkable example of curved scorings may be seen on a broad, flat, smoothed surface of Potsdam sandstone 2½ miles east-southeast of Alexandria Bay, about ½ mile west of three corners. The bare area lies in the track and on the north side of an abandoned highway, on land of John Bogert. The locality is indicated by three converging arrows on plate 47, and one photograph is given in plate 59.

Curved glacial scorings on planed Potsdam sandstone, 2½ miles eastsoutheast of Alexandria Bay. Looking downstream, south 56° west. The scorings curve to south 44° west. H. L. Fairchild, photo, 1908

A considerable area of planished rock is covered by striae which have various directions, from s. 56° w. to s. 16° w. Apparently the markings with the more westerly trend are the older and prevailing ones over most of the surface, the later and more southerly abrasion having softened the older groves and given a cross polish. But the later motion is also represented by a few strong chatter bands which quite obliterate the older scorings where the latter are crossed.

The curved markings lie in a belt about 10 feet wide and over 50 feet in length now exposed. The scorings are strong, clean-cut, and perfectly parallel. At the north end they lie for several yards perfectly straight, with direction 56° west of south, then they gently curve, southing with steady uniform curvature until the direction is s. 42° w. The curving is still continued where the belt of scorings passes under the turf on the south side of the wagon track. The strong furrows may not be confidently traced throughout the entire length of the curve in distinct individuality, as later abrasion has somewhat obscured them in places, but they are practically continuous and retain their relation and character. The belt of curved scorings is exceptional to the general striae of the broad surface and surrounding bare patches, the prevailing direction being s. 30–35° w.

The curving lines have no angularity and show no hesitation nor pauses or spasms in the ice motion. In one place a few of the strong scorings in a narrow strip exhibit a perceptible variation from the true curvature, or a tendency to straightness, but taking the belt as a whole the curvature and the parallelism of the lines appear to the eye to be true. The radius of the curve is about 60 or 70 feet. The chord of the exposed belt, including about 15 feet of the straight beginning of the scorings, is 54 feet; and the ordinate is 23 inches.

This glaciated surface is the northern side of a broad rock plain, with no apparent cause in the surrounding topography for the deflection in the ice flow. A narrow valley lies near on the north, across which is a somewhat higher plain. The map, plate 44, shows the general topography.

A significant fact is that the curving belt of scorings, even at the southern deflected end, so far as uncovered, is much more westerly in trend than the prevailing ice movement, not only in the immediate locality but in the great area.

Chatter marks and gouges. The innumerable exposures of the Potsdam sandstone, often of large extent, coupled with the very hard and brittle texture of the rock, furnish many excellent ex-

amples of the effect of the dragging pressure and the percussive force of the boulder-shod ice. The rock is too hard to accept much furrowing or mass removal on the flat surfaces, but its brittleness favors the production of fractures due to compression and to striking force. Of these features two classes will be briefly described.

The hard boulders held as planes and hammers in the bottom ice have produced two kinds of curving fractures, one class convex upstream or toward the boulder, the other convex downstream or concave toward the boulder. Those with the concavity facing downstream, that is to say, with the convexity toward the producing tool, fall under the category of "cones of percussion" or "chatter marks." Many excellent examples of these concentric fractures are seen, some of large size or up to 10 inches of arc and forming from one quarter to one third of the circle. Sometimes the parallel concentric fractures are closely crowded, several within an inch, but are usually somewhat more open, three or four or less to the inch. Figure 13 is traced from a "rub" taken by the road near the house

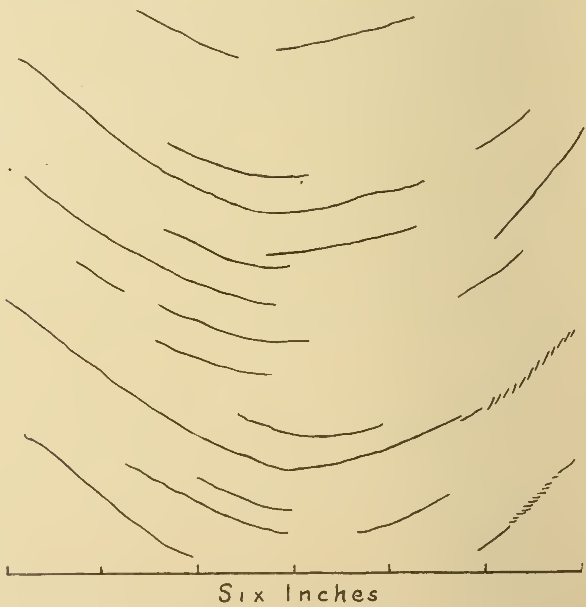


Fig. 13 Chatter fractures

of William Northrup, 3 miles northwest of Redwood and 3 miles east of Alexandria Bay, and about 3/4 of a mile northeast of the curved scorings described above. In this case 11 fracture lines lie within 4 inches along the axis of the curvature, most of them being

short. The longer lines have an arc of 6 inches or a radius of about 3½ inches.

Another excellent illustration of the chatters is on the highway 3 miles north of Redwood on the road to Chippewa Bay, at the point indicated on plate 47. Several very large examples occur in the middle of the street in Redwood village, just below the Dollinger House. Smaller examples are so very numerous that no notebook record was made of them. Fine examples occur with the curved scorings.

The chatter fractures dip so steeply into the rock that rarely is there any flaking of the surface rock. In many instances no axial grooving or crushing of the rock is visible, the appearance being as if the rock had been abraded and resurfaced and polished so as to leave merely the clean-cut concentric fracture lines. Such abrasion is more than possible but is very slight, as early striae having the direction of the axes of the chatters are not obliterated. Commonly there is some evidence along the axial line of the pressure by the unsteady or chattering tool.

The other class of fractures, having the concavity facing upstream toward the tool, are much less regular or true than the chatter fractures. In both classes the cracks dip downstream or away from the point of the tool, but in these gouge fractures the angle of dip is much less than in the chatters, and commonly there is considerable flaking of the rock or removal of the feather edges of the surface rock. These cracks fall in the class of "concentric gouges" or "disruptive gouges" of earlier writers.[1] The action seems to have been a sort of drag or pull on the surface of the rock by pressure of a boulder with broad area of contact, but without pounding or percussive force. The process was a plucking by dragging pressure.

These gougings are not as common as the chatters, and only two good localities were noted. One of these is ¾ mile south of the county line between Jefferson and St Lawrence counties, on the west road to Chippewa Bay. The other occurrence is on the road east of Goose bay and on the south side of Crooked creek valley. The first mentioned is on the south end of a plain, the latter on a surface facing north, where the ice was pushing against an upslope.

The gouge fractures are rarely true circular curves, in which cases they may be mistaken for chatters, but commonly they are irregular

[1] A full description and discussion of these singular phenomena connected with glacier mechanics is given in Professor Chamberlin's paper Rock Scoring of the Great Ice Invasion. U. S. Geol. Sur. An. Rep't 1888. p. 216–40. Reference to other writings is there given.

in both form and relation. They lack concentric parallelism, in other words are not in regular series; and they are not always transverse or normal to the line of motion of the tool, as shown by the band of crushing or gouging. Figure 14 shows these characters.

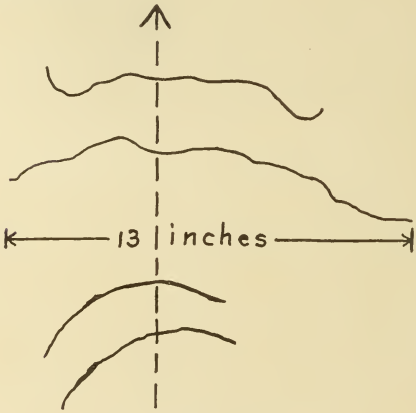


Fig. 14 Gouge fractures

To summarize: the gouge or dragging fractures would seem to be the effect of a steady dragging motion of a boulder with large contact surface, while the chatters are the product of unsteady, percussive or pounding movement of points of boulders or small contact surfaces.

Limestone flutings. Over large districts in the southern part of the limestone area the rock surface is worn into series of parallel, cylindrical ridges of several feet diameter, separated by equally regular troughs or hollows. These features which can be attributed only to ice erosion are illustrated in plates 60–63. As the amount of erosion and the direction of the ribs and ice movement are inconsistent with the work of the latest ice sheet the discussion of the topic is deferred to the next chapter.

Prewisconsin glaciation

Theoretic considerations. In the preceding pages several features have been mentioned as difficult of explanation or inconsistent with the conception of a single ice invasion. The facts and argument favoring the view of multiple glaciation will be summarized here.

If the generally accepted conclusions of glacialists, that the northeastern states have been repeatedly glaciated since Tertiary time, are well founded, it is quite impossible to except or exclude New York from all ice invasions earlier than the latest, or Wisconsin. The several glacial epochs recognized in the Mississippi valley have been named on page 137. The very old drift of New Jersey and southeastern Pennsylvania is believed to be as old, certainly, as the Kansan, and probably represents the Preaftonian, which is now sometimes called the Jerseyan when referring to the

eastern region. The drift of northwestern Pennsylvania lying in advance of the Wisconsin drift, is believed to be as old at least as the Kansan. For an ice sheet to so expand as to reach either northwest or southeast Pennsylvania without trespassing on New York seems impossible. Hence we are forced to the belief, apart from any evidences on the ground, that the State has been more than once in the climatic condition of Greenland at the present time.

If the State has been overrun by ice sheets more than once it seems rather strange that geologists have not recognized the phenomena and discriminated the records. It must be admitted that we now lack the evidence afforded by multiple till sheets, separated by temperate climate deposits such as are found in the Western States. With attention directed to this subject it is probable that some conclusive proofs will be discovered.

But while no single fact or class of phenomena yet found furnishes conclusive proof of more than one ice epoch, we have a variety of indirect evidences, and many features are well explained only on that supposition, and several lines of study converge toward that conclusion. Moreover, to attribute all the glacial phenomena to a single ice sheet involves inconsistencies, such as the evidence of impotence in erosion of the latest ice, with indication of vigorous erosion formerly; and the lack of glaciation surfaces on ice-shaped rock as well protected as places showing hairline striae and polish.

The glacial features of the Thousand Islands region which are not satisfactorily referred to the latest ice work probably can not be attributed to an ice sheet as ancient as the Kansan, but would seem to be the effect of some recent ice epoch. Whether it was one of the later Prewisconsin invasions or only an early Wisconsin episode we may not now decide.

Anomalous physiography. South of our area, in the central part of the State, many channels of ancient drainage are found which are not Postwisconsin. In the area under discussion these features do not occur because the whole region was drowned in deep water during the ice recession. But the region has its own peculiar topographic features that are difficult of full explanation under the conception of a single ice transgression. The valley, basin and scarp topography has already been briefly discussed [p. 146]. Other points will be touched on below, but a full discussion of the difficult problem requires more fieldwork specially directed to the particular features.

Old till. As far as the writer is informed, the first one to recognize Prewisconsin till in New York was F. B. Taylor. In the summer of 1905 he directed attention to the very compact, resistant, stony, blue till in the bottom of the deep valleys southeast of Buffalo, which he confidently pronounced older than the overlying and prevailing Wisconsin drift. Subsequently the writer noted other occurrences of similar till. In 1907 Frank Carney published an account of what he regarded as old till in the Keuka valley.[1]

No soil zones or forest grounds lying between the supposed old till and the superfical till have yet been found, to prove the fact of an interval of deglaciation, though such finds may be expected. The writer has noted very sharp distinctions between the two tills, with incorporation of the lower into the upper. An important locality is along the new cuttings for the shortened tracks of the Delaware and Hudson Railroad west of Schenectady, between Kelly station and Duanesburg. Here an incoherent, yellow till, capped with gravel, directly overlies a very hard, dark blue till. The contrast between the two is very striking and the line of separation is very distinct in some sections; while in places the older blue till has been plowed up and masses have become incorporated in the yellow till. The blue till retains its color and consistency even when exposed for considerable time to the weather, masses which have lain in the field over the winter being only partially disintegrated. The writer was told that the steam shovels were able to cut the blue "hardpan" with much difficulty and very slowly.

The blue till has a very different composition and derivation from the overlying and oxidized yellow till. It is impossible that an ice sheet, producing from its burden of ground-up shale and limestone the hard blue till, should suddenly cease to deposit this and at once lay down a yellow oxidized till of entirely different origin. We have here good proof of at least two distinct episodes in ice work.

The writer has not noted in our Thousands Islands area any example of tills comparable to the old, blue tills farther south, though Cushing thinks that he has seen them. But they probably do occur just south of the boundary, in the northern part of the city of Watertown. Here begins a group of drumlins that extends southward. In the mass of the drumlin forming the dome-shaped hill north of the Black river, and in the small drumlin ridge in the northwest corner of the city, where the Dexter electric line crosses

[1] Pre-Wisconsin Drift in the Finger Lake Region of New York. Jour. Geol. 15:571-85.

Postglacial weathering. Open joint across limestone ribs, 1½ miles east of Dexter. Looking northwest. H. L. Fairchild, photo, 1907

the Cape Vincent branch of the New York Central Railroad, a hard, gray blue till appears that is very unlike the prevailing drift of the northward area. The latter exposure is shown in plate 52. The resemblance of this drumlin till to the "old" tills farther south is as close as might be expected when the differences in latitude, source of the material, etc. are considered. However, we must recognize that the drumlin till was subglacial, deposited beneath the ice and under tremendous grinding pressure; while the surficial drift of the area was dropped in standing water, and is consequently incoherent, sandy, inclined to yellow or gray colors, and carry few striated or abraded stones. The production of masses of subglacial drift or drumlins is a sort of work which the later ice did not do north of Watertown, at least to noticeable extent, and it is doubtful if it did such work at Watertown. However, the drumlin till is inconclusive, until we know if the Watertown drumlins are the work of the latest ice or of some earlier invasion. This Watertown till is not in valley bottoms or deeply buried, but in hills above the levels of the plain.

Limestone ribbing. Over the southern part of the Clayton quadrangle the limestones frequently exhibit series of parallel ribs or flutings, a sort of washboard structure on a vast scale [pl. 60–63]. These ribs positively have no genetic relation to the joint structure of the rock. They are pronounced convexities, often quite cylindrical but commonly rather flat, with a breadth from crest to crest, or across the base, from 2 to 10 feet; the usual breadth being 3 to 5 feet. The hollows between the ribs are usually filled with drift or soil, but when cleared they show quite cylindrical troughs of uniform width and fair curvature, and parallelism with the ribs. By solution-weathering the sides of the flutings are rarely steepened and the bottoms perforated by solution holes, as in plate 63.

Within any single exposure these flutings are strikingly parallel [pl. 61] and are approximately so over the whole region, having a direction about s. 45° w. Scores of them have been measured with that direction, over all the area between Dexter and St Lawrence village. The extreme variation in direction is s. 40° w. for the heavy ribbing east of Dexter, and s. 50° w., south of Dexter, shown in plate 63. Two other localities toward St Lawrence gave the latter compass direction.

Speaking broadly the flutings have lost all their glacial surfaces, retaining only the erosional form, for their origin by ice erosion of the limestone seems certain. In a very few cases a suggestion of the heavier scorings are preserved, and some minor flutings on the

ribs. The ribs which have been long exposed have been so corroded by weathering that one might question even their glacial origin. But those flutings also which are only recently uncovered have lost their glaciated surface, though they may show the perfect polish of a later glaciation oblique to the ribbing. This fact is important with reference to the age of the ribbing.

In plate 61 we see a typical example of the ribbed limestone, the locality being the west side of a hollow several rods west of the railroad station at Threemile Bay. The ribbing is s. 45° w. The three ribs in the foreground at the lower right corner have been strongly cut and polished by an ice flow having direction s. 55° w. This change of 10 degrees in direction is not unusual for the same ice sheet, and taken alone would be weak evidence of dual glaciation. The important fact here is that the later ice movement has scored and polished the ribs obliquely, striking them on the east faces, and the later polishing is perfectly preserved though apparently has been exposed as long as other portions of the ribs where no glaciation is visible. The ribs are being freshly uncovered by the wash on the slope, but the only glaciation seen is that oblique to their direction. The only reasonable inference is that the ribs have lost the glacial surface by old age weathering and that the oblique polish is from a later ice rubbing. The ribs are rough and corroded where not cut by the more westerly planing, and it is certain that the lack of striae and polish on the ribs can not be due to merely recent weathering.

The ribs and hollows have no fixed relation to the joints of the rock. In the locality of plate 61, while the ribbing is s. 45° w., the joints, so far as they have any dominant trend, are s. 75–85° w. Nowhere are the joints so true and parallel as the ribbing. Only occasionally do joints appear in the furrows but they commonly lie boldly across the ribs and are frequently opened widely, as in plate 60, where some joints are a foot wide and 10 feet deep. The removal of the clays of the latest deposits from the ribbed surface shown in plate 60 has been chiefly by subterranean drainage through these open joints. It seems very unlikely that these open joints were produced with their present size and form since the last glaciation and beneath several feet of the Dexter clay [pl. 58]. The joints certainly are the product of atmospheric weathering and solution, and it seems a safe inference that they represent a time of long exposure antedating the last ice work.

These exposed ribs east of Dexter, visible on the north side of the electric line, lie in a hollow in the clay, as shown in plate 63,

Plate 61

Glacial ribbing in limestone, Threemile Bay station. Looking north 35° east. Compare plates 62 and 63. Direction of ribs s. 40° w. Recent glaciation in lower right corner, s. 55° w. H. L. Fairchild, photo, 1908

Plate 62

Weathered rib of limestone, 1½ miles west of Brownville, south side of Black river. Looking southwest. Compare plates 61 and 63. H. L. Fairchild, photo, 1908

Glacial flutings in limestone, ½ mile southeast of Dexter. Looking n. 50° w. Compare plates 61 and 62. Directions of ribs s. 50° w. H. L. Fairchild, photo, 1908

the hollow being produced partly by the washing of the clay cover down the wide solution joints. On the sides of the hollow the ribs are being newly uncovered by the storm wash and the tramping of cattle, but no trace of glacial polish was seen, the new surfaces being similar to the longer exposed surfaces of the middle of the ribs. Masses of chert standing 2 or 3 inches above the limestone surface prove a long period of solution of the rock surface, which seems impossible beneath the present clays in the short time involved. Enforcing this conclusion is the fact that only a number of rods distant, in the gutters of the electric road under similar clay cover the same limestone shows elegant glaciation. But while the ribbing is s. 40° w. the preserved glacial scorings are variable, ranging from s. 50° w. to s. 10° e.

These two examples of the ribbing, which can be multiplied, will give illustration of the quality of the evidence they offer in favor of at least dual glaciation in recent time. These flutings are widespread, remarkably uniform in direction (generally s. 42–45° w.), symmetrical and true in form. They can not be attributed to weathering, nor jointing, nor wave work, nor water corrosion, all of which have left conspicuous records in the district. Undoubtedly the ribbing is old glacial, and it represents a glacial abrasion vastly more energetic than the similar work of the latest ice sheet.

Weathered surfaces. The considerable weathering which the limestones have suffered is shown in plates 23, 26, 27 and 63. Doubtless some part of this corrosion is postglacial, specially on the more exposed patches and on cliff edges where the rock was not buried by the drift; but it must not be assumed that these etched, corroded and open-jointed surfaces were all left smooth and glaciated by the latest ice sheet, as that is the question under discussion.

The uncovering of corroded surfaces which have been under clay that would seem to have been sufficient protection from the postglacial weathering, as illustrated in plates 61 and 62, argues strongly for nonglaciation of such surfaces. The conditions shown in plate 60 seems to prove that great open joints existed in the limestones previous to the deposition of the glacial clays.

Probably many of the deeply corroded surfaces were recently buried under ice or lake deposits which have been swept off by the wave erosion of the standing waters and the subsequent and now acting storm wash. Without more special study on the ground it is impossible to estimate the amount of postglacial weathering. In some places it seems very small, and where slightly covered prac-

tically nothing. Such cases give the impression of slight corrosion since the ice removal. On the other hand the existence of broad surfaces of exceedingly rough and open-jointed rock, from which the farmers have to fence their cattle, and the location of which would seem to have been favorable to glaciation, give the suggestion of large postglacial weathering. The critical question is, were the latter surfaces glaciated by the latest ice sheet? It would appear that a duration and intensity of postglacial weathering which has not destroyed the glacial polish on the limestone ribs shown in plate 61 could not justly be held responsible for the open joints and rough surfaces shown in plate 60, where a deep clay cover has been removed chiefly by washing down into the open joints and being carried away by subterranean flow.

The amount of recent weathering is conspicuously greater in locations where the surfaces have been subjected to wave wash of the Iroquois and Gilbert waters, this being specially effective in both solution and mechanical removal of the limestone.

Old planation surfaces. If the ribbing on the limestone was in existence before the last ice invasion then, of course, the limestone plains and plateaus were formed previously; and it has already been stated that the broader topographic features are confidently believed to antedate Wisconsin glaciation. An ice sheet with sufficient vigor to do the plucking and planing necessary to give the limestones and Potsdam sandstones their breadth of flatness should leave abundant evidence in glaciated surfaces; and the limestone ribbing is a relic of such effective erosion. Again, the general lack of glacial polish is the fact which requires explanation.

The plains of Potsdam sandstone present the same question. Over broad surfaces of the very firm, hard, insoluble sandstone, either bare or practically unprotected by any impervious cover, only a minor part exhibits striae or polish. Certainly it was once all vigorously glaciated, for in no other way could the level, even, firm surfaces be produced. From hasty examination it is impossible to confidently decide whether the patchy scoring and polishing is due to weak recent glaciation on an old weathered surface, or to retention of polish under present weathering. The former alternative, recent partial smoothing on an old weathered surface, is more in harmony with the general body of fact; and it seems more probable that the recent ice sheet failed to generally polish the old weathered surface than that patches with finest polish and hairline striae should be so perfectly preserved while surrounding surfaces

with apparently identical physical conditions have lost all traces of recent glaciation.

Weak erosion of the Wisconsin ice sheet. It will be seen that the critical point in this study is the erosional impotence of the latest ice sheet. With this established then at least dual glaciation of the region must be accepted.

The principle is recognized by glacialists that intensity of ice erosion depends on pressure, velocity of the bottom ice, and its armament or tools. The glacier can do its most effective work of abrasion when the basal ice is only moderately charged with rock rubbish, and that of hard texture. A heavy burden of subglacial drift serves to diminish the plasticity of the ice and so reduce the velocity of flow; while at the same time it acts as protection or a buffer for the subadjacent rock. For this reason rapid corrasion is a self-checking process.[1] On the other hand it is certain that clear ice can not abrade the bed rock at all. A moderate load of hard tools is the most effective for abrasion.

The first ice sheet that transgressed our region found it deeply covered with the residual product of millions of years of weathering, and could do no effective erosion until not only the sheet of geest (regolith) on our area had been removed but also that lying on the region northward into Labrador and Canada which was swept by the southward ice flow. The theoretical stages would be as follows: (1) the scraping away of the decay product and bearing it far southward, as no very heavy moraines lie near our area; (2) vigorous erosion during the phase of favorable load, with harder tools from the plucking of the fresher rocks; (3) weak abrasion by the clearer ice after the glacier had swept its floor and reduced the asperities in its path.

On the postulate of a single ice invasion of the Thousand Islands region it is necessary to assume that after the ice had removed the abundant product of Prepleistocene weathering it used its medium load of debris to plane the hard Potsdam and to plane and deeply flute the limestone, but at the same time failed to rub down the scores of comparatively abrupt cliffs and scarps which opposed its motion. Here we find another inconsistency. Without further discussion it will be understood that the assumption of a single glacial epoch involves serious contradictions and difficulties in the explanation of the phenomena of the region.

Assuming dual or multiple glacial epochs the features and history are fairly clear. The accumulations of long eras of rock weathering

[1] Geol. Soc. Am. Bul. 16:26.

were swept southward by the earlier glaciation. Later ice work with more abrasive power planed the harder stratified rocks, grooved the limestones, modified the topographic forms by softening the scarps and rock knobs and straightening the drainage lines. One or more long interglacial epochs partially restored the characteristic atmospheric-erosion forms of the Theresa and Pamelia scarps and cuesta fronts; reexcavated the valleys and basins; and destroyed the surficial glaciation on the sandstones and limestones. The latest ice sheet finding the northward region denuded of rock debris and smoothed by the earlier glaciation was unable to arm itself for effective erosion and thus handicapped was competent only to weakly abrade in places. It is possible that while the deglaciation interval in our district produced some weathering effects the northward (Labrador) region was continuously snow-covered and the ice was not able to pluck a new supply of granitic tools.

Undoubtedly there were important differences in the behavior and mechanical effects of the several ice sheets, due to differences in rate of accumulation and velocity of flow; of depth and pressure; of temperature and rate of waning; and these combined with, and an effect of, climatic variations.

It would have been entirely proper in this writing to have assumed multiple glaciation and confidently to have explained the singular features of the area on that basis. Perhaps the method of argumentation which has been used is somewhat confusing to the reader, but he will better appreciate the complexities of the study and its consequent fascination.

ECONOMIC GEOLOGY[1]

While the district under consideration is bordered on the east by an area in which hematite, pyrite, galena and talc have been, or are being, mined, none of them have been found in anything like workable quantity within the limits of the map. The ferruginous quartz schists of the Grenville are present in quantity but are very lean ores indeed. One mile north of Theresa on the Red lake road a small opening has been made on a hematite mass which occurred as a direct replacement of Grenville limestone. The material was a finely crystalline, scaly, specular iron, and was of great purity, but there were only a few tons of it. While therefore the deposit was of interest as a clear and pretty example of replacement of the sort, it had no economic value.

[1] By H. P. Cushing.

Small masses of barite are not infrequent in the Grenville limestone, but none were seen of any size or importance. An old opening was made on a coarsely micaceous limestone contact zone, 2 miles north of Theresa, but no mica of merchantable size and quality was forthcoming.

The only mineral industry of the district that has any present or prospective value is the quarry industry. Stone has been and is being quarried for road metal, for paving, for flagging, for lime, and for construction. Various Precambric rocks, the Potsdam sandstone, and the Pamelia, Lowville and Black River limestones have all been quarried in varying degree for one or the other of these purposes.

Road metal

Road improvement is going on hereabout, as elsewhere in the State. About Theresa, Grenville limestone has been chiefly used, though a small quarry has been opened in very impure limestone cut up by granite, which furnished very variable, and hence not very good material. The limestone from the other quarry makes a very good macadamized road, as would apparently much of the Grenville limestone of the district.

About Alexandria bay various experiments have been tried with road metal. The Laurentian granite gneiss of the vicinity has been used, and of course given poor satisfaction. To a small extent Pamelia limestone has also been used, and has not proved very satisfactory, probably because of the variability of the different layers used, pure limestone and magnesian limestone probably being mixed together. At present a considerable stretch of road north of Browns Corners is being macadamized with Grenville amphibolite, obtained 1 mile west of Redwood, surfaced with Grenville limestone, which, as we saw it being obtained, was of poor quality. The amphibolite was slightly soaked with, and cut by granite, so that the material was not as uniform as is desirable, but the quantity of granite is so slight that the lack of uniformity is not prominent, and the amphibolite itself is quite undecayed, firm and strong. It seems on the whole likely to prove quite adaptable to road-making purposes. Its composition is quite similar to that of trap, and in all probability it will bind in similar fashion.

Potsdam sandstone has been used as a road rock to a small extent. It is absolutely unfitted for such use, and the worst rock that could be selected for the purpose.

In the southern part of the mapped district the Lowville, Black River and Trenton limestones have been used on the roads, and all serve the purpose very well.

The rock of the district best fitted for road metal has, as yet, not been utilized at all, namely that of the trap (diabase) dikes. There is no better road metal known than trap, provided it be unrotted, and the wide dikes which occur on Grindstone island are capable of furnishing a considerable supply of material, much of which is certainly quite fresh. The material is in large demand for road-making purposes.

On the country roads to the eastward of Alexandria Bay, on which travel is light, the easily rotting, aluminous phases of the ferruginous quartzite (Grenville) have had considerable use for surfacing the roads, and answer the purpose satisfactorily.

Granite quarries

During the past season both the Picton granite and the Laurentian were being quarried in the district. The former rock has been intermittently quarried on Grindstone island for a number of years and has been considerably used for structural and ornamental purposes, both locally and at a distance. For uses for which pronouncedly red granites are serviceable it compares very favorably in appearance and quality with the other red granites of the country. There is much quite uniform material available, and large sized blocks can be quarried. In 1908 none of the Grindstone island quarries were being worked, though quarrying was actively in progress on Picton island, where the chief quarries of today lie.

On the mainland, a short distance west of Alexandria Bay, active quarrying operations are in progress in the Laurentian granite gneiss. At the location the rock is fairly uniform and free from inclusions, and is being quarried for paving blocks, which are being shipped to Chicago for use. Transportation to the various cities on the Great Lakes is of course cheap, and the rock seems well adapted to the purpose for which it is being used.

Sandstone quarries

Various small openings have been made in the Potsdam sandstone here and there in the district, for very local building and flagging purposes. Just beyond the Alexandria sheet edge, to the east, in the town of Hammond, the Potsdam forms a long scarp, at the base of which the railroad runs, and the rock here is quarried largely

for paving blocks. It is fairly evenly and thinly bedded here, mostly of red color, well indurated, and quite well adapted to the purpose. The same would be true of much of the Potsdam of the adjacent portion of the Alexandria sheet, were it as conveniently situated as regards transportation.

Limestone quarries

There are many of these in the district, quarrying the Pamelia, Lowville and Black River limestones, both for structural purposes, and for burning for lime. The massive 7 foot tier of the Black River is largely quarried, the large solid blocks obtainable rendering it an exceedingly serviceable material for heavy masonry construction, much more so than the thinner bedded Lowville and Pamelia limestones. Some of the beds of the upper Lowville are also fairly thick, make very serviceable stone where construction is less massive, and hence are quarried in many places. Most of the Pamelia is much thinner bedded, and the thicker beds are mostly separated from one another by much thin bedded material. Nevertheless the formation contains some good stone, and there are numerous quarries in it all the way from Leraysville to west of Clayton, which, however, chiefly serve a local use in the northern part of the mapped area. It is not so largely quarried and used as the upper Lowville. The dove limestones of the upper part of the formation should, it would seem, make an excellent cement rock.

A single quarry has been opened in the impure, thin beds of the upper division, a few miles south of Clayton, and the stone used for flagging in Clayton. Owing to the joints only medium sized slabs can be obtained, but otherwise the rock is fairly smooth surfaced and makes a very respectable flagstone.

The quantity of limestone in the district available for these various uses is enormous, and the nearness of water transportation bespeaks a considerable future for the industry.

PETROGRAPHY OF SOME PRECAMBRIC ROCKS[1]

It is proposed here to treat, in somewhat more detail than seemed suitable in the general account, of certain of the Precambric rocks with discussion of chemical analyses. While some of the igneous rocks of northern New York have already received detailed study, more especially the syenites and certain gabbros, others have been comparatively neglected, notably the granites. For the purpose of

[1] By H. P. Cushing.

somewhat atoning for this neglect, analyses have been prepared of four samples of granites of the region, as shown in the following table:

	1	2	3	4	5	6
SiO_2	76.56	76.41	73.33	73.10	70.13	66.59
Al_2O_3	12.95	12.41	13.55	14.29	15.47	14.54
Fe_2O_3	.16	1.01	.58	1.04	1.52	2.42
FeO	.37	.50	1.53	1.04	1.05	2.43
MgO	.24	.46	.45	.53	.85	1.18
CaO	1.30	.78	1.66	1.18	1.60	2.15
Na_2O	3.90	3.34	5.01	3.08	3.72	3.08
K_2O	4.23	4.33	3.12	5.36	4.39	5.62
H_2O+	.25	.34	.45	.54	.48	.46
H_2O-	......	.13		.07	.01	....
TiO_2	.06	.03	.17	.18	.30	.81
ZrO_2	......	.02	......	......	......	....
P_2O_5	......	......	......	.03	......	.40
Cl	.04	......	......	.03	.05	.03
F	.03	.01	......	.02	.09	.06
S	.02	.01	......	.02	.07	.08
MnO	.02	.06	.04	.07	.08	.23
BaO	.02	......	......	......	.05	.17
	100.15	99.84	99.89	100.58	99.86	100.25

NOTE. Cr_2O_3 and CO_2 absent in nos. 1, 4, 5 and 6.

1 White (bleached) granite near limestone, 1 mile north of Redwood (5K10, Alexandria sheet), from a small boss of Laurentian granite gneiss. Analysis by E. W. Morley.

2 Morris granite of Long Lake quadrangle, one of the later granites of the region. N. Y. State Mus. Bul. 115, p. 511.

3 Laurentian granite gneiss from the Methuen bathylith of central Ontario. F. D. Adams, Jour. Geol. 17:17.

4 Laurentian granite gneiss of the Alexandria bathylith, ¼ mile south of Alexandria Bay (6E5, Alexandria sheet), analysis by E. W. Morley.

5 Laurentian granite gneiss of Antwerp bathylith, 2 miles east of Theresa (16M4b, Theresa sheet), chosen for analysis because of apparent slight digestion of amphibolite. E. W. Morley, analyst.

6 Picton granite, from a quarry 1 mile southeast of Grindstone, Grindstone island (2F3, Grindstone sheet). Analysis by E. W. Morley.

That the granite gneisses hold abundant amphibolite inclusions in various stages of digestion, so that the rock is quite variable in composition, has already been stated. The rock of analysis 4 was carefully selected as representative of the normal, acid phase of the rock, free from amphibolite contamination. It is a quite normal, rather acid granite, and comparison with analysis 3 shows close agreement except that the relative proportions of the alkalies are

reversed in the two. Calculation of its norm gives the following result:

Or	31.69		Class I, persalane
Ab	26.20		
An	5.00	95.29	Order 4, britannare
Co	1.50		
Qz	30.40		Rang 2, toscanase
Hy	2.46	4.44	
Il & Mt	1.98		Subrang 3, toscanose

The rock of analysis 5 was not the normal acid granite gneiss of the locality where it was collected, but somewhat darker colored, more basic in appearance, and the field relations definitely suggested that it had soaked up some amphibolite. Nevertheless the analysis shows that this contamination is in slight amount, and the rock is to be classified in the same group as its predecessor, as its calculated norm shows.

Or	26.13		Class I, persalane
Ab	31.44		
An	7.51	93.85	Order 4, britannare
Co	1.83		
Qz	26.94		Rang 2, toscanase
Hy	2.50		
Il & Mt	2.70	5.49	Subrang 3, toscanose
Py	0.29		

The mode of these rocks differs so little from the norm that it is not thought worth while to present the calculation. Both rocks consist chiefly of feldspars and quartz, with biotite as the principal additional mineral, a little magnetite, and trifling amounts of apatite, zircon, titanite, muscovite and pyrite. These minerals taken together only amount to about 6% in the first case and 8% in the second. In each case the surplus of alumina in the norm, calculated as corundum, is in just the proper amount to combine with the magnesia to form biotite.

Bleached granite

The rock of analysis I is from the margin of a small granite boss-cutting limestone, north of Redwood, which we regard as being of Laurentian age, and is a fresh sample of granite whitened by adjacent limestone. It is a somewhat more acid rock than the preceding. Unfortunately no samples which seemed satisfactory

for analytical purposes could be obtained from the adjacent red granite of the same boss, and this white granite stands as the only border rock of any of the granites which has been analyzed. The field relations of all the granite masses indicate that their border zones, and the dikes which run out from them, are more acid than the general mass of the rock, higher in quartz and with much less biotite and magnetite. Now the granite cuts and sends dikes into all the Grenville rocks, all of this more acid phase, yet it is only in the case of adjacent limestone that the border and the dikes become white. In the schists and quartzites they remain red, though equally acid with the white. In so far then as the higher silica and lower iron of the white granite are concerned, the rock is believed to be merely an average representative of the general, more acid border rock, it being confidently held that much of the red, border granite or dike granite would show equivalent acidity, and like diminution in iron, and that the color change is in no way concerned in these differences. Though no chemical analyses are available, study of slides of these acid red granites gives results in close accord with the analysis of the white, and many of them show almost no biotite and magnetite in the rock, hence they are much poorer in iron than the rock of analysis 4, though with feldspar equally as red in color. Slight differentiation has taken place in the granite, producing more acid borders and dikes, and these bleached only by limestone.

The rock classes as a toscanose, as do the others. Yet it is close to the border line between orders 3 and 4, as shown by its close similarity in composition with the red, Morris granite of analysis 2, which falls in order 3 and is an alaskose.

There is every reason to believe that the coloring matter of the red feldspar is ferric oxid; in fact in some of the thin sections, minute, red hematite scales are readily made out with high powers. In casting about for some chemical explanation of the bleaching of the feldspar, chance put me in communication with Dr W. F. Hillebrand, who most generously furnished me such data as he had at command. He writes as follows:

Many years ago, in Denver, I had occasion to analyze a zeolite that was colored red by iron oxid. On ignition the red color disappeared entirely and almost pure white resulted. This was undoubtedly due to a combination between the iron oxid and the silicate material. My impression is that the zeolite was a calcium-aluminum silicate. Since then I have seen in the *Chemical News*, vol. 84, p. 305, a reference to the decolorizing effect of alumina on ferric oxid when the two are ignited together . . .

Now on hearing of your problem it occurred to me that such an effect might be represented by the bleached dikes in limestone. The idea was that, under the influence of the intrusions, the limestone may have become decarbonated to a slight extent, thus facilitating action with the ferric oxid of the feldspar. The explanation does not, however, satisfy me, for one might expect perhaps that the feldspathic material intruded at the elevated temperature would have already acted on its iron oxid, and hence not show color; still it may be that the silicate molecule of the feldspar is far more resistant than the zeolite and limestone in respect to ferric oxid, which might thus be in independent existence with the feldspar at high temperatures.

Dr Warth's article in the *Chemical News* deals with the blowpipe ignition of mixtures of alumina and ferric oxid in various proportions, in which the color invariably changed from red to white when small amounts of iron were used, while a brownish tint was obtained when the proportions were larger. Incidentally it was also shown that the alumina prevented reduction of the iron to the magnetic oxid.

A sample of finely crushed and sorted red granite was ignited by us for three hours over a Bunsen flame in a platinum crucible. The portion in close contact with the sides and bottom became white, while the bulk of the material, in more central position and hence less strongly heated, retained its red color. This we take to indicate that, with sufficiently high temperature, even in feldspar, the red color will disappear, and that the presence in rocks of alkali feldspar colored red by ferric oxid shows that, under the conditions of congelation, the temperature was not sufficiently high to bring about this color change. We then mixed a small quantity of powdered limestone with another charge of the crushed granite, and ignited in the same crucible over the same burner for the same time. Not only was the feldspar of the entire charge bleached, but the bleaching seemed complete at the end of one hour. Finally we ignited a third charge, in which a very thin coating of limestone was spread over the top, but not mixed with the granite as in the previous case, and here again the bleaching was prompt and absolute. It is not intended to imply that the cause of the bleaching was the same in both cases, but only that, in the presence of lime, decoloration took place more readily and at a lower temperature; precisely what the field relations had indicated for the granite in place. There is also here, it seems to us, a hint at the reason why red coloration is a common feature in alkali feldspars, and not in lime soda feldspars.

The amount of ferric oxid in the red feldspar is undoubtedly very trifling, so that, if chemical combination has taken place and the lime has entered into the reaction the quantity involved is so small that it would be a comparatively insignificant feature in the complete rock analysis. It is to be noted that the lime is somewhat higher in analysis 1 than in 4, but, while it is possible that this is owing to lime taken up from the limestone and going into combination with the iron of the feldspar, it must be remembered that the variation is well within the limits of variation which all the bases show in the general granite mass, hence it is absolutely unsafe to generalize in regard to it. We may have a combination of lime, iron and alumina in a spinellike mineral, though lime does not, in general, occur in spinel; or a small amount of anorthite may be formed, with the iron replacing alumina. The iron may perhaps be reduced, forming an iron aluminate, the iron reduced to the ferrous condition, though it would seem as if this would likely give a green color to the feldspar. Warth argues that his color changes need not mean chemical combination of the two oxids but rather a diffusion of one in the other. Hillebrand, however, is quite confident that combination takes place. He says, "It is unquestionable that both lime and alumina decolorize and combine with ferric oxid when they are heated together." Though this chemical question must be left indefinite, it does seem to us certain that the red color of the feldspar may be made to disappear merely by sufficiently high and prolonged heating, that the presence of lime facilitates the process, lowering the necessary temperature, and that with our feldspars here the temperatures were not sufficiently high to discharge the color, or rather to cause the feldspars to crystallize with the iron combined, rather than as free hematite, under the conditions prevailing at the place and time of solidification; though they were high enough to cause the combination to take place when in the vicinity of limestone and under its influence.

The only difference in the mineralogy of the two rocks is the presence in the white rock of occasional, scattered, small black tourmalins, which in general do not appear in the other, though they are locally present even there. They would seem attributable to the presence of mineralizers in the border phase of the granite, and in the dikes they occur in the red granites adjacent to other rocks than limestone, such as quartzite for example, and seem to have nothing whatever to do with the color change. It seems to us that the chemical analysis gives no suggestion whatever as to the cause of this change.

Picton granite

The specimen of Picton granite analyzed was selected as an average representative of the rock, and bears out the impression gained in the field that as a whole it is less acid than the Laurentian granites where uncontaminated by Grenville material. It seems less quartzose, and always shows considerable hornblende, which is relatively scarce in the granite gneiss. The thin section shows it to be fairly rich in accessory minerals, titanite and apatite especially being frequent and fairly coarse, the former particularly so. Some pyrite is present, zircon also, little hematite inclusions in the feldspars, and ilmenite or rutile needles in the quartz. A few minute tourmalin crystals also occur. The green hornblende is altering to biotite, and there is additional biotite in the rock as well. For the feldspars, microperthite, microcline, microcline-microperthite and oligoclase are all present in considerable amount, and all with strongly marked characters. A good deal of micropegmatite, some of it quite coarse, is also to be seen. Altogether, in its minor mineralogy, the rock presents considerable contrast to the granite gneiss.

The norm of the rock is a follows:

Or....	33.36	89.00	Class 1, persalane
Ab....	26.20		Order 4, britannare
An....	8.62		Rang 2, toscanase
Qz....	20.82		
Hy....	4.48	10.64	Subrang 3, toscanose
Mt....	3.48		
Il.....	1.52		
Py....	0.15		
Ap....	1.01		

It thus falls in the same rock group as the granite gneisses, but is much nearer the border of the group than they are. The greater variety and abundance of the femic and alferric minerals, hornblende, biotite and titanite, would cause the mode to depart somewhat more widely from the norm than in the previous cases, the lime to form titanite being deducted from the anorthite, releasing alumina for the biotite and diminishing the quartz percentage.

The dike phases of this granite range more acid than this, but with this exception it is thought that the average of the rock composition is well represented by the analysis. The composition is

toward the basic end of the granites, hence it is not surprising that slight variations toward further basicity should give rise to rock with little quartz, like that south of Clayton along French creek. Except for this the petrographic agreement is so close in all details that there seems no question as to the identity of the two rocks.

Alexandria syenite

In the previous description of this syenite it has been stated that an augen gneiss adjoins it on the south which was taken by us in the field for a gneissoid, border phase of the rock, but that Smyth dissents from this view. In the field this border rock appears much the more basic of the two, but closer examination shows the presence of much quartz, and chemical and microscopic investigation shows it to be much more acid than the syenite. Analyses of each follow, with two analyses of the general Adirondack green syenite, thought to be represented in this district by the Theresa syenite, (of which no analyses have been made) for purpose of comparison with them.

	1	2	3	4	5
SiO_2	58.99	59.70	63.45	66.50	66.59
Al_2O_3	19.22	19.52	18.38	15.66	14.54
Fe_2O_3	2.83	1.89	1.09	1.75	2.42
FeO	2.83	4.92	2.69	2.21	2.43
MgO	1.25	.78	.35	1.18	1.18
CaO	3.41	3.36	3.06	2.15	2.15
Na_2O	4.33	5.31	5.06	3.74	3.08
K_2O	5.64	4.14	5.15	5.02	5.62
H_2O+	.35	.52	.30	.40	.46
H_2O-	.04			.05	....
TiO_5	.01	.....	.07	.71	.81
P_2O_2	.59	.....	.....	.59	.40
Cl	.10	.....	.....	.06	.03
F	.40	.....	.....	.05	.06
S	.08	.....	.....	.18	.08
MnO	.14	.9	trace	.03	.23
BaO	.09	.....	.....	.05	.17
	100.30	100.23	99.60	100.33	100.25

1 Alexandria syenite, 3½ miles north of Redwood (8K2, Alexandria sheet). E. W. Morley, analyst.
2 Tupper syenite (laurvikose), N. Y. State Mus. Bul. 115, p. 514.
3 Loon Lake syenite (pulaskose), N. Y. State Mus. Bul. 115, p. 514.
4 Augen gneiss associated with Alexandria syenite, 2 miles west of north of Redwood (6J2, Alexandria sheet), E. W. Morley, analyst.
5 Picton granite, repeated from previous column of analyses.

Norm of Alexandria syenite, analysis 1:

Or....	33.36	87.15	Class 1, persalane
Ab....	36.68		Order 5, Canadare
An....	11.12		Rang 2, pulaskase
Co....	1.85		Subrang 3, pulaskose
Qz....	4.14		
Hy....	5.00	11.30	
Mt....	4.18		
Fl....	0.78		
Ap....	1.34		

The rock itself contains considerable green horblende and biotite which, together with the accessory magnetite, titanite, apatite and pyrite, constitute about 15% of the rock, (elsewhere they run up to 25 or 30%, carrying the rock into the dosalane class) meaning of course that some of the lime, alumina and potash calculated with the salic minerals of the norm are in the hornblende and biotite. Microcline, microperthite and oligoclase are all present in some quantity, plagioclase being somewhat in excess. Some of the microperthite is secondary after oligoclase. The rock has beautiful cataclastic structure, showing much more crushing than the Picton granite. Chemically it is seen to be very close to the green syenites of similar silica percentage, the chief difference being in the higher magnesia and in the relative proportions of ferric and ferrous iron and of the alkalies. The higher magnesia expresses itself mineralogically in the formation of hornblende and biotite, instead of the pyroxenes of the green syenite. The general rock is somewhat more basic, and with a higher percentage of ferromagnesian minerals than the normal green syenite.

The augen gneiss of analysis 4 is a much more acid rock, a toscanose, suggesting caution in attempting to account for it as a phase of the syenite. The analysis is so close to that of the Picton granite of the last column as to be almost grotesque. Quite certainly it has no relation whatever to the Picton granite, though mimicing it so closely chemically. The green syenites of the region show wider range of variation than that shown in this case, nevertheless the intrusion here is of such comparatively small size that variation in composition to this amount would be quite unusual. Hence the analyses rather tend to reinforce Smyth's conclusion that we really have here two separate small intrusions, side by side.

Mineralogically the augen gneiss consists of quartz, feldspars and biotite, with accessory magnetite, titanite and apatite, and

small amounts of hornblende, muscovite, zircon and pyrite. The femic minerals constitute 15% of the rock analyzed. The feldspar is chiefly microcline and oligoclase, though with some microperthite. Both feldspars occur as augen, with trains of granulated material running away from them, between which are foliae of quartz, feldspar and biotite. To a considerable extent the quartz and biotite seem to have resulted from recrystallization of feldspar.

The certain Alexandria syenite runs into very gneissoid and micaceous border phases, which lie between its massive core, and the augen gneiss beyond. These varieties are much more micaceous, and much more quartzose than the massive portion, and in them also much biotite and quartz have resulted from feldspar recrystallization. They are thus very similar to the augen gneiss. It was this apparent gradation from one rock to the other in the field which gave us the impression that the whole represented a single intrusion. It is a matter of very minor importance in the local geology, and must for the present be left as undetermined.

Granitized amphibolite and amphibolitized granite (soaked rocks)

Practically all observers who have worked in Laurentian areas, have seen and recorded the evidences, which meet one on every hand, of the attack of the granite upon the amphibolite inclusions, large and small, which occur nearly everywhere, and are often abundant. The action consists of an injection of granite into the amphibolite, at first along the foliation planes, from which the granite spreads out more or less into the adjacent rock, injecting itself between and inclosing the grains, but with the distinction between the two materials still sharp. In later stages this sharpness disappears, the two materials seem to merge, or fade into one another, and as a final stage a rock is produced which seems a true mixed rock, in which a distinction between the two elements is no longer possible, and whose origin would be problematic except for the occurrence of the less advanced phases of the change. Needless to say the granite must be very thoroughly molten in order to produce these mixed rocks. It was our purpose to investigate these rocks somewhat thoroughly chemically. Unfortunately however no material which seemed to us sufficiently fresh to warrant chemical investigation was obtained from rocks which seemed distinctly intermediate. A beginning was made, however, by the investigation of two rocks, one a granite slightly tinctured with amphibolite, and the

other an amphibolite slightly soaked by granite, and their analyses appear herewith. Each, in the field, was classified as plainly a soaked rock, in which the constituents were merged. Each was also merely a phase in a gradual increase in amount of soaking, plainly to be traced in the field, and the two samples were chosen from among many because of unusual freshness.

	1	2	3	4	5
SiO_2	73.10	70.13	56.58	51.42	50.83
Al_2O_3	14.29	15.47	15.54	17.42	18.64
Fe_2O_3	1.04	1.52	3.80	3.64	2.84
FeO	1.04	1.05	5.41	5.14	5.97
MgO	.53	.85	2.77	5.11	4.90
CaO	1.18	1.60	4.56	6.76	7.50
Na_2O	3.08	3.72	2.91	3.74	4.22
K_2O	5.36	4.39	4.25	3.33	1.83
H_2O+	.54	.48	.80	.74	1.40
H_2O-	.07	.01	.10	.09	
TiO_2	.18	.30	1.71	1.25	1.10
ZrO_2	......	......	.01	.01	....
P_2O_5	.03	......	.87	.71	....
Cl	.03	.05	.12	.13	.03
F	.02	.09	.14	.10	....
S	.02	.07	.44	.23	.01
MnO	.07	.08	.09	.16	.10
BaO	......	.05	.08	.13	.11 CO_2
	100.58	99.86	100.18	100.11	99.48

NOTE. Cr_2O_3 and CO_2 absent.

1 Laurentian granite gneiss of Alexandria bathylith, from column 4 of original table.
2 Laurentian granite gneiss of Antwerp bathylith, slightly soaked with amphibolite, column 5 of original table.
3 Amphibolite, somewhat soaked by granite, from railroad cut 4 miles north of Redwood (8L2a, Alexandria sheet). E. W. Morley, analyst.
4 Amphibolite, from same railroad cut (8L2B, Alexandria sheet). E. W. Morley, analyst.
5 Amphibolite described by Adams as representing the extreme stage in the alteration of crystalline limestone into amphibolite by contact action of the Glamorgan bathylith, Jour. Geo. 17:2.

It is not thought that the amphibolite of analysis 4 is an altered limestone, but rather a member of the schist series, though likely a calcareous shale, even perhaps an impure limestone. In any case its similarity in composition with the amphibolite described by Adams from Maxwells Crossing is quite striking, the somewhat higher magnesia and potash being the most prominent differences.

Adams also shows, in his valuable paper, the similarity in composition of his contact amphibolite with other amphibolites, even some of igneous origin. It would seem therefore that we are reasonably safe in assuming that analysis 4 will not depart widely in composition from most of the amphibolites of the region, no matter what their origin.

The analyses of the two granites have been already discussed. No. 2 does not depart widely from no. 1 in composition, and might well represent a simple variant of the magma. Its field relations, however, preclude that supposition and it is to be noted that, when compared with analyses 1 and 4, it represents an intermediate stage in every single important constituent. On the basis of the silica percentage a mixture of six parts of analysis 1 and one part of analysis 4 would almost give a rock of the composition of analysis 2. Calculated on that basis the following result is arrived at:

	1	2	3	4
SiO_2	70.13	70.05	56.58	56.62
Al_2O_3	15.47	14.73	15.54	16.66
Fe_2O_3	1.52	1.42	3.80	3.01
FeO	1.05	1.63	5.41	4.14
MgO	.85	1.18	2.77	3.97
CaO	1.60	1.99	4.56	5.53
Na_2O	3.72	3.17	2.91	3.58
K_2O	4.39	5.08	4.25	3.79

In column 1 are given the percentages of the soaked rock shown by analysis, and in 2 the calculated percentages on the basis stated above. They seem to us to be sufficiently alike in every constituent to afford a strong probability that the field relations were correctly interpreted, and that the rock is a true soaked rock. The greatest variation between the two is in the alkali percentages, and these are just the ones which vary most in the general granite masses. The total amount of alkalies, however, is much the same in each, 8.11% in the first case and 8.25% in the second.

The granitized amphibolite is not so definitely a soaked rock as the other, since the amount of granite in it is so small, that it is an impregnated, rather than a mixed rock. Nevertheless the granite is thoroughly disseminated through it, though granitizing it in patches rather than uniformly. Column 3 gives the rock percent-

ages of this amphibolite, and column 4 a calculated mixture of granite and amphibolite in the ratio of 24% of the former and 76% of the latter. The agreement in this case is not so close as in the former one, but in large part the differences can be ascribed to the fact that the granite here is not normal, but of the pegmatitic type, higher in mineralizers and in iron, and poorer in alumina, lime and magnesia than the normal rock. Comparison of analyses 3 and 4 seems definitely to suggest this, the iron being higher in the granitized rock than in the amphibolite, and the lime and magnesia much lower. It is thought that if an analysis of the neighboring granite was available for use in the computation, the agreement would be much closer. But the result is somewhat disappointing, and the importance to be assigned to the discrepancies a debatable matter, likely to vary with the personal equation of the reader. Considering all the circumstances the agreement seems to us as close as could be hoped for, and indicative of the correctness of interpretation of the field evidence, namely, that these are true mixed rocks.

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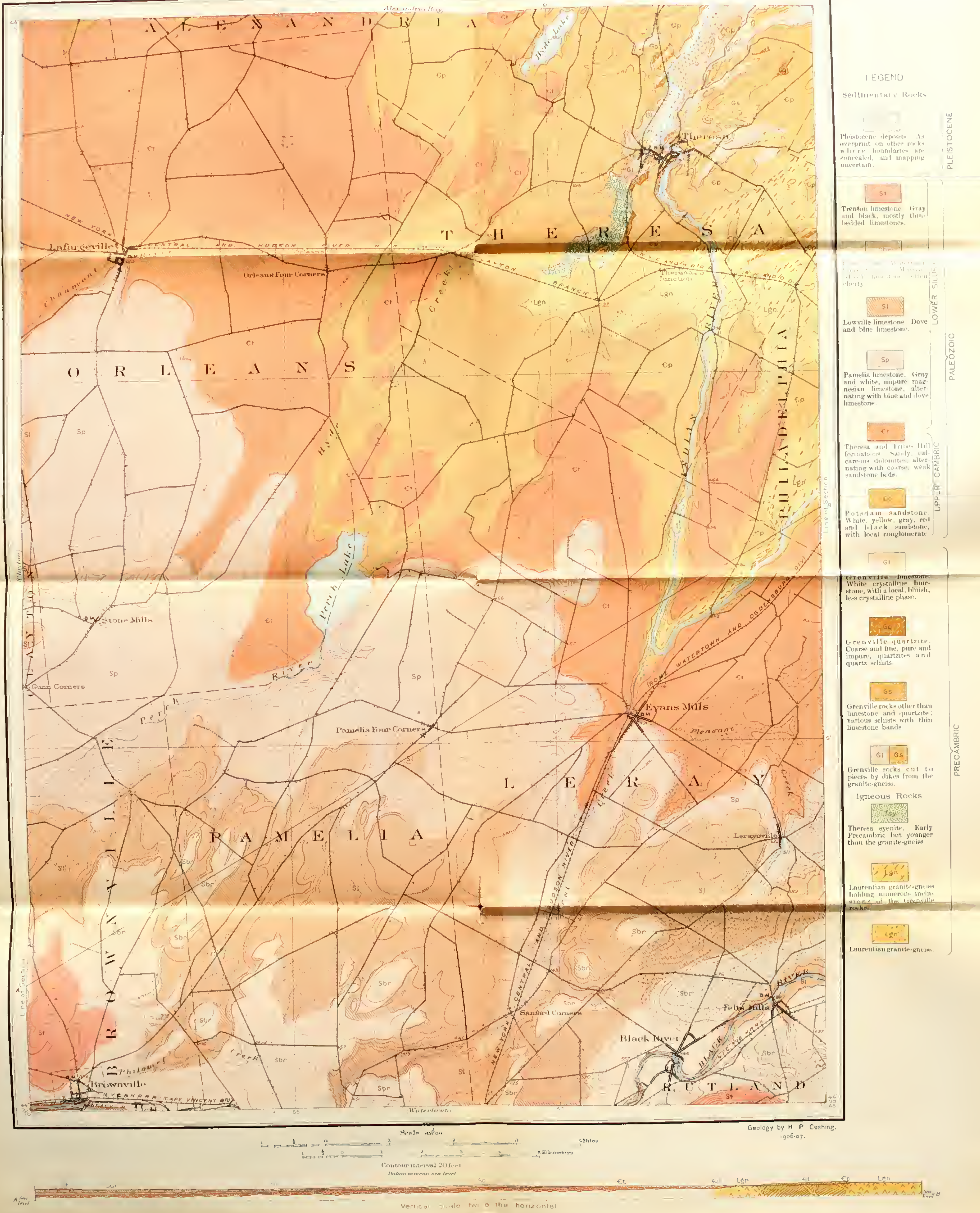
ALEXANDRIA
THERESA
ORLEANS
PHILADELPHIA
LERAY
PAMELIA
BROWNVILLE
RUTLAND
Theresa
Lafargeville
Orleans Four Corners
Stone Mills
Gunn Corners
Perch Lake
Evans Mills
Pamelia Four Corners
Leraysville
Felts Mills
Black River
Sanford Corners
Brownville
Watertown
LEGEND
Sedimentary Rocks
Pleistocene deposits. As overprint on other rocks where boundaries are concealed, and mapping uncertain.
Trenton limestone. Gray and black, mostly thin-bedded limestones.
Lowville limestone. Dove and blue limestone.
Pamelia limestone. Gray and white, impure magnesian limestone, alternating with blue and dove limestone.
Theresa and Tribes Hill formations. Sandy, calcareous dolomites, alternating with coarse, weak sandstone beds.
Potsdam sandstone. White, yellow, gray, red and black sandstone, with local conglomerate
Grenville limestone. White crystalline limestone, with a local, bluish, less crystalline phase.
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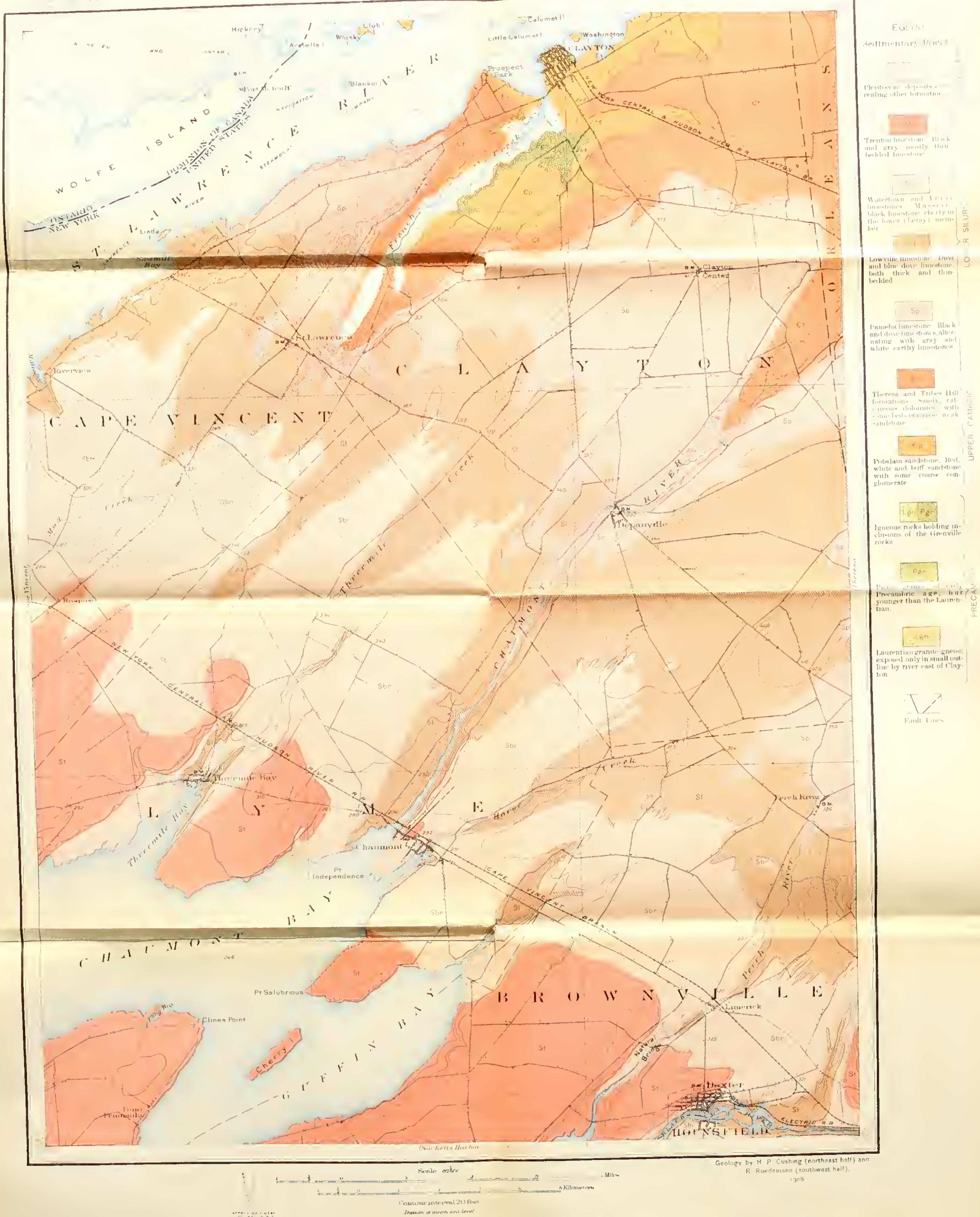
Igneous Rocks
Theresa syenite. Early Precambric but younger than the granite-gneiss
Laurentian granite-gneiss holding numerous inclusions of the Grenville rocks.
Laurentian granite-gneiss
PLEISTOCENE
LOWER SILURIAN
UPPER CAMBRIC
PALEOZOIC
PRECAMBRIC
Geology by H. P. Cushing. 1906-07.
Contour interval 20 feet
Datum is mean sea level
Vertical scale twice the horizontal


LEGEND
St
Trenton limestone Black and gray, mostly thin bedded limestone
Sbr
Watertown and Leray limestones Massive black limestone cherty in the lower (Leray) member
Sl
Lowville limestone Dove and blue dove limestone both thick and thin-bedded
LOWER
KINGSTON
ST LAWRENCE RIVER
Cedar Id
Garden Id
Ferguson Pt
Milton Id
The Spectacles
Howe Island
Halliday Pt
LONG ISLAND
BIG BAY
Mud Id
Carleton Id
BUTTON BAY
Alexandria Point
REED BAY
SAND BAY
Long Point
Bear Point
DOMINION OF CANADA
UNITED STATES
CAPE VINCENT
Fuller Bay
Wilson Pt
Wilson Bay
Mud Creek
Stony Pt
Mud Bay
Baird Pt
Fox Creek
Grenadier Id
Fox Id
CHAUMONT BAY
LYME
LAKE ONTARIO
Stony Island
Geology by R Ruedemann
1908
Scale
Miles
Contour Interval 20 feet
Datum is mean Sea level

STATE MUSEUM




HYDROGRAPHY
OF THE
THOUSAND ISLANDS REGION
H. L. FAIRCHILD
1909
LEGEND
Preglacial divide between eastward and westward waters, now crossed by the diverted Black River
Present divide between St
KINGSTON
BROCKVILLE
EDWARDSBURGH
WADDINGTON
OSWEGATCHIE
MORRISTOWN
DEPEYSTER
MACOMB
HAMMOND
DEKALB
CANTON
GOUVERNEUR
HERMON
ROSSIE
ALEXANDRIA
ANTWERP
PITCAIRN
CLAYTON
ORLEANS
CAPE VINCENT
LYME
PHILADELPHIA
LE RAY
WILNA
DIANA
BROWNVILLE
CHAMPION
CROGHAN
WATERTOWN
RUTLAND
HOUNSFIELD
DENMARK
HENDERSON
ADAMS
RODMAN
PINCKNEY
HARRISBURG
NEW BREMEN
LOWVILLE
WATSON
ELLISBURG
LORRAINE
WORTH
MONTAGUE
MARTINSBURG
GREIG
SANDY CREEK
BOYLSTON
REDFIELD
HIGH MARKET
WEST TURIN
LYONSDALE
RICHLAND
ORWELL
OSCEOLA
LEYDEN
LANSDOWNE
LEEDS
FRONT OF YONGE
FRONT OF ESCOTT
AUGUSTA
LAKE ONTARIO

Geology by H. P. Cushing and C. H. Smyth, Jr
1908

Education Department Bulletin

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New York State Museum

JOHN M. CLARKE, Director

Museum Bulletin 146

GEOLOGY OF THE NEW YORK CITY (CATSKILL) AQUEDUCT

STUDIES IN APPLIED GEOLOGY COVERING PROBLEMS ENCOUNTERED IN EXPLORATIONS ALONG THE LINE OF THE AQUEDUCT FROM THE CATSKILL MOUNTAINS TO NEW YORK CITY

BY

CHARLES P. BERKEY

ALBANY

UNIVERSITY OF THE STATE OF NEW YORK

1911

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New York State Education Department
Science Division, April 6, 1910

Hon. Andrew S. Draper LL.D.
Commissioner of Education

SIR: The extraordinary engineering operations which have been undertaken in the effort to provide the city of New York with an adequate water supply have illuminated in most unexpected manner the geological structure and history of the region of the Hudson valley south of the Catskill mountains. So broad has been the scientific scope of this engineering problem and so direct its dependence on geological structure that the Commissioners of the New York City Board of Water Supply early found it of essential moment to enlist in their service a corps of trained geologists.

In 1909 an agreement was effected between the Board of Water Supply and the State Geologist, in pursuance of which the geological data acquired in the preliminary and final surveys for the aqueduct were intrusted to Dr Charles P. Berkey, a member of the staff of the board as well as of the geological survey, for summation and presentation of their broader and more important bearings.

I transmit to you herewith Dr Berkey's report thereupon, entitled *Geology of the New York City (Catskill) Aqueduct.* It is a document of high value not only in enlarging and perfecting our knowledge of the geological structure of the commercial center of the United States, but its data and conclusions must prove of profound importance to all large engineering and architectural propositions concerned with the region of the lower Hudson valley.

I therefore submit this, subject to your approval, for immediate publication as a bulletin of the State Museum.

Very respectfully

JOHN M. CLARKE

Director

State of New York
Education Department
COMMISSIONER'S ROOM

Approved for publication this 7th day of April 1910

A. S. Draper

Commissioner of Education

Plate I

The Catskill and Croton water supply systems of New York city

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BY

CHARLES P. BERKEY

INTRODUCTION AND ACKNOWLEDGMENT

It is the writer's hope that the series of studies brought together in this bulletin may help to effect a wider appreciation of the practical usefulness of geology. The volume contains a summary of the local geologic facts and the general principles found helpful in solving some of the problems encountered in a single great engineering enterprise. The summary is accompanied by brief discussions of the methods employed and of the final results or conclusions reached. It is therefore essentially a study in applied geology.

Seldom has so favorable an opportunity been afforded to follow extensive exploratory work and check geologic hypothesis or theory by subsequent proof. And still more seldom have engineers in charge of similar works so fully appreciated the value of geologic investigations and the extent to which they can be utilized as a guide.

More credit is due to Mr J. Waldo Smith, chief engineer of the Board of Water Supply of the City of New York, than to any one else for appreciating the importance of the geologic complexity of

the Catskill Aqueduct problem. His exceptional insight into its nature led to the adoption of measures in this direction that are now proved to have been fully justified. A staff of geologists has been maintained. From time to time engineers of the regular staff who have shown unusual aptitude in such investigations have been assigned to special duty on geologic exploratory work. In the preliminary investigations of the Northern Aqueduct, Division Engineer James F. Sanborn was very intimately connected with the geologic work. With him the writer worked out many field studies that later formed the basis of advisory reports, covering locations, kinds of explorations to be made, and interpretations of data. No one has had a better grasp of both the geologic and the engineering aspects than Mr Sanborn. It is with great pleasure that the writer acknowledges many valuable suggestions and much help through association with him. In the later exploratory work within the city similar service has been rendered by Mr John R. Healey, who has much to do with the geologic detail of the delivery conduit data. The consulting geologists employed by the board were Professors James F. Kemp, W. O. Crosby and the writer.

A special debt is acknowledged to Prof. James F. Kemp, consulting geologist of the board, whose confidence in the writer's work originally brought him into touch with these investigations as an assistant, and with whom since that time many joint reports to the board have been written.

Valuable advice and assistance in arranging for the issue of this report has been given by Department Engineer Alfred D. Flinn of Headquarters Department. For some of the corrections and suggestions special acknowledgment is made to Department Engineer Thaddeus Merriman.

The department engineers, Robert Ridgway of the Northern Aqueduct, Carlton E. Davis of the Reservoir, Merritt H. Smith, formerly of the Southern Aqueduct, Frank E. Winsor of the Southern Aqueduct, William W. Brush and Walter E. Spear of the City Delivery have given every facility for gathering geologic data within their territory and have contributed largely to the better understanding of their special fields.

The geologic matter relating to special problems has been worked out with the aid of the division engineers in direct charge in the field. Among these must be mentioned L. White of the Esopus division, William E. Swift of the Hudson river division, A. A. Sproul of the Peekskill division, Lawrence C. Brink of the Wall-

kill division, J. S. Langthorn of the Ashokan reservoir, Wilson Fitch Smith of the Kensico division, T. C. Atwood of the New York city delivery division.

The data included in the tabulation of this bulletin have been gathered largely by others. Many of the explanations and conclusions are the outgrowth of the work of engineer and geologist, together. A large number of associates are engaged on this public work in such relations to one another that the individuality of each is obscured in the common effort to reach an enviable efficiency and success for the whole enterprise.

The combined efforts of many, unselfishly given, have thus brought together a total far in excess of what any one individual could accomplish. Acknowledgments should therefore be made to those members of the staff of the Board of Water Supply who can not in the nature of the case be mentioned by name. Were it not for their cooperation the great mass of data here summarized could not have been compiled.

Charles P. Berkey
Special Geologist, New York State Geological Survey;
Consulting Geologist New York City Board of Water Supply
Columbia University, New York City November 1, 1910

I

GENERAL FEATURES

CHAPTER I

CATSKILL WATER SUPPLY PROJECT

New York city obtains its chief water supply from the Croton river watershed. Other sources[1] now drawn upon are less important although some of them, such as the Long Island underground supply, are capable of considerable additional development. The average daily consumption of Croton water was approximately 324,000,000[2] gallons for 1907. At the present rate of increase of population the consequent daily increase in consumption of water is 15,000,000 gallons in each succeeding year.

The entire daily flow of water in the Croton river for the 18 years from 1879 to 1897 averaged only 348,000,000 gallons. About 10,000,000 gallons per day is lost by evaporation and seepage from existing reservoirs. The records for 40 years, from 1868 to 1907 make a somewhat better showing. Making no allowance for evaporation the average flow amounts to 402,000,000 gallons. With due allowance for evaporation,[3] however, this only increases the daily supply as now planned by about 47,000,000 gallons. That is, the possible total additional water within the Croton watershed would suffice for only three years' growth of the city. Much of this additional water belongs to periods of excessive precipitation. To save it would require additional storage facilities for 305,000,000,000 gallons, and, it is estimated, would probably cost $150,000,000.

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[1] Brooklyn is in part supplied by these additional sources which furnished 145,000,000 gallons daily in 1907.

[2] The figures used here as to consumption and capacity and available supply are taken from the printed statements of the commissioners of the New York City Board of Water Supply in a circular dated April 16, 1908, and are based upon the investigation and reports of the corps of engineers headed by J. Waldo Smith, chief engineer, John R. Freeman and William H. Burr, consulting engineers. The reports of this commission and various others that have had the responsibility of investigating the future supplies for New York city have been drawn upon freely for such data.

[3] The average rainfall for the past 40 years is about 49 inches per year. Only about 48 per cent of this runs into the streams. The rest evaporates or is absorbed by the vegetation or joins underground supplies that do not again appear at the surface in the district.

Taking into account the small relief possible in this direction and the certainty that in less than five years the demands of the city will be greater than the total capacity of the Croton watershed, it is clear that some other source of large and permanent supply is an absolute necessity.

In the search for such additional sources, there has been much careful work done by able commissioners.[1] In the meantime, residents of certain districts where there are possible supplies have taken steps by legislative action to effectually[2] prevent New York city encroaching upon their territory. Criticisms[3] of all kinds largely by those only partially informed as to the magnitude and complexity of the problem and partly by those ignorant of the simplest factors in its solution, have been kept perpetually before the public. One needs only a slight acquaintance with such public works to realize that it is much easier and more common to criticize and raise the cry of corruption or incompetence than it is to give really valuable advice or solve a real problem or carry an enterprise of the most vital public importance to a successful issue.

It is sufficient here to observe that exhaustive studies of the whole question of water supply by competent men have resulted in a practically unanimous conclusion that the streams of the Catskill mountains are the most satisfactory, economical, reliable, abundant and available future source of water.

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[1] The Report of John R. Freeman C. E., 1899-1900; Report of the Burr-Herring-Freeman Commission, 1902–4; the Studies of the Department of Water Supply, Gas and Electricity, 1902–4; Investigations of the Board of Water Supply, 1905 to the present time.

[2] Acts of the Legislature of 1903–4.

[3] The commonest suggestions neglect the question of permanence or constancy of supply. The following sources are often mentioned, (*a*) Lake George, forgetting that this beautiful lake has an abnormally small watershed and could never figure as a large permanent supply; (*b*) artesian wells, ignoring the fact that with the exception of certain portions of Long Island there is almost no artesian capacity, and on Manhattan and the mainland the crystalline rocks make such development useless; (*c*) Lake Ontario, apparently overlooking the great distance (400 miles) and the many other complications that this international water body involves; (*d*) the Housatonic river, neglecting the difficulties of interstate origin; (*e*) Dutchess county, where the city is prohibited by legislative enactment; (*f*) the Hudson river, ignoring the fact that the Hudson is an estuary of the sea with brackish water of a very impure quality and wholly unfit for domestic uses. It is, however, worth while to note that Hudson river water is sure to be used more and more extensively for fire protection and similar purposes in the more densely populated portions of the city by means of an entirely different system of conduits. This is one of the most promising directions of relief looking to the more distant future.

The Catskill supply will furnish over 500,000,000 gallons of water daily and was estimated to cost $161,857,000. That is, the additional supplies from the Catskills as planned will, when completed, be sufficient for the increasing demands of the growing city, for the next 35 years. And some of it may be badly needed long before it can possibly be delivered.

Parts of the Catskill system[1]

The chief sources within the Catskills now included in the plans of the board are:

1 Esopus creek, to be taken at a point near Olive Bridge.

2 Rondout creek, to be taken at a point near Napanoch.

3 Three small streams tributary to the Rondout.

4 Schoharie creek, to be taken at a point near Prattsville.

5 Catskill creek, to be taken at a point about 1 mile northeast of Durham.

6 Six small streams tributary to the aqueduct between Catskill creek and Ashokan reservoir.

The comparative areas of watershed and their daily capacity are estimated[2] by the corps of engineers as follows:

	AREA IN SQUARE MILES	STORAGE IN GALLONS	DAILY SUPPLY IN GALLONS
1 Esopus watershed..........	255	70 000 000 000[3]	250 000 000
2 Rondout watershed........	131	20 000 000 000	98 000 000
3 Three small tributaries.......	45	....	27 000 000
4 Schoharie watershed........	228	45 000 000 000	136 000 000
5 Catskill watershed.........	163	30 000 000 000	100 000 000
6 Six small streams..........	82	....	49 000 000
Total..................	904	165 000 000 000	660 000 000

[1] The subdivisions and proposed locations given here are taken chiefly from the Report of the Board of Water Supply of the City of New York to the Board of Estimate and Apportionment, October 9, 1905.

[2] Estimates are much more complete for the Esopus, which it is planned to develop first, than for any other streams; and it must be understood that the figures are subject to revision dependent upon modifications of original plans to meet the conditions that develop upon more elaborate investigation.

[3] Preparations are to be made for storage of 120,000,000,000 gallons of water on the Esopus, but a part of this capacity is intended to accommodate supplies drawn from other sources than Esopus creek itself.

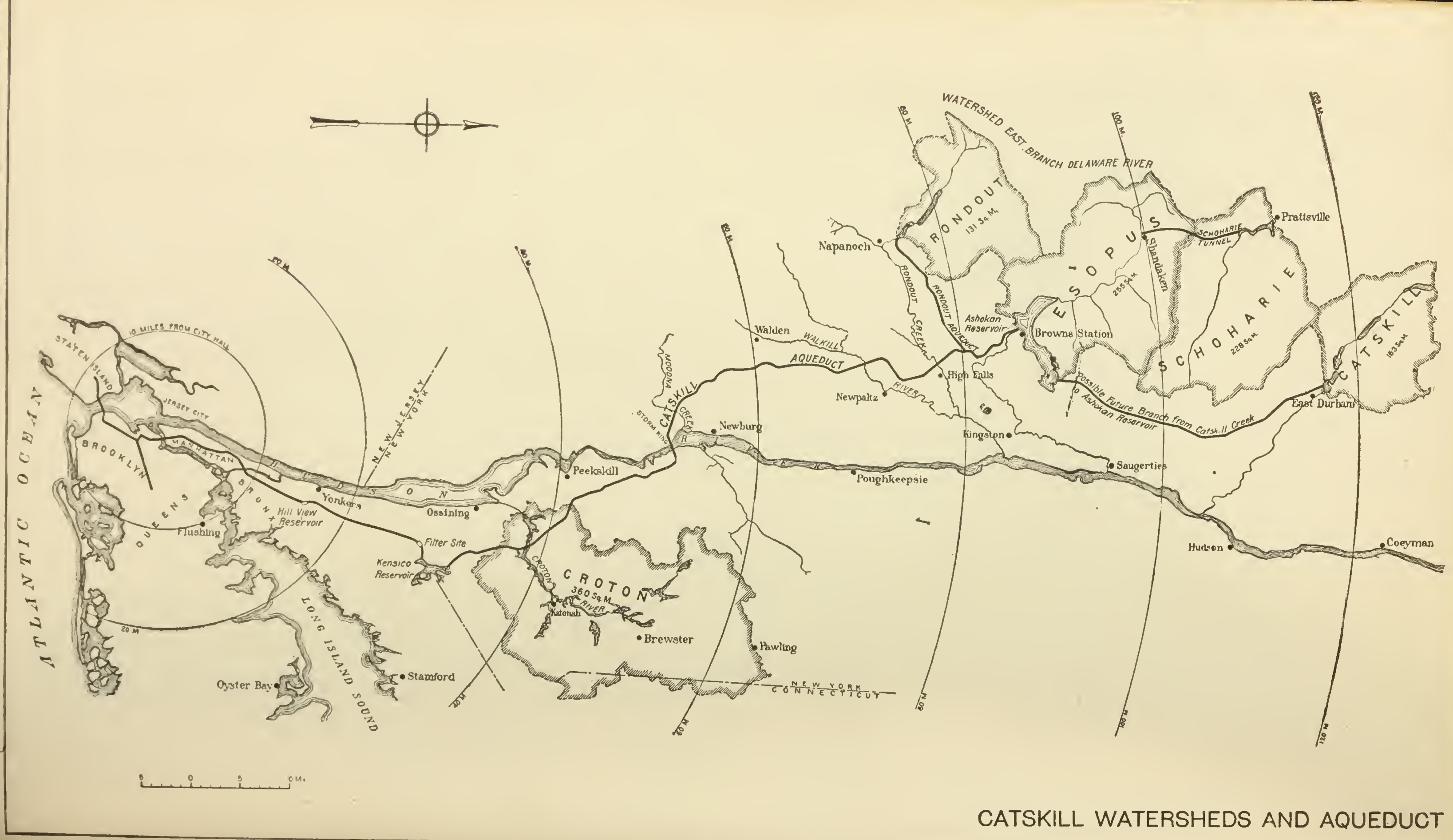

Fig. 1 Outline map showing the different catchment basins of the New York water supply system and the Catskill Aqueduct. (By courtesy of the Board of Water Supply.)

The evident certainty that present supplies from the Croton and Long Island will be very inadequate long before the Catskill system can be completed has influenced the adoption of plans contemplating the construction of certain parts in advance of the rest. To begin with, only the Esopus watershed is to be developed by the construction of the great Ashokan dam at Olive Bridge making the reservoir of full capacity. At the same time that portion of the aqueduct between the Ashokan dam and the present Croton reservoir is to be completed in advance of other parts so as to make it possible to turn additional supplies into the Croton system, the capacity of the present Croton aqueducts being somewhat in excess of the Croton storage in dry years. It is furthermore desirable that increased storage capacity should be secured much nearer to New York city, and with that end in view Kensico reservoir is to be greatly enlarged. It is estimated that this may be made to hold 50 days' supply of 500,000,000 gallons daily.

The development of the Catskill system is being carried on by the Board of Water Supply, which was appointed by Mayor McClellan, as provided in chapter 724, of the laws of 1905. The present board consists of John A. Bensel, *president,* Charles N. Chadwick and Charles A. Shaw. The Engineering Bureau of the Board is in charge of J. Waldo Smith, as chief engineer, Merritt H. Smith, as deputy chief engineer and Thaddeus Merriman, assistant to chief engineer.

Influenced doubtless in large part by the unity of certain portions of the project, either because their essential engineering features are distinct, or because their construction is more urgent, or in order to facilitate the work of supervision of so great an undertaking, the following departments have been created:

1 Headquarters department (executive). In charge of general designs, plans of construction and preparation of contracts. Alfred D. Flinn, department engineer.

2 Reservoir department. In charge of development of the Catskill watershed and the construction of the various dams and reservoirs. Carlton E. Davis, department engineer.

3 Northern aqueduct department. In charge of the construction of full capacity aqueduct from the Ashokan dam (60 miles) to Hunters brook in the Croton system. Robert Ridgway, department engineer.

4 Southern aqueduct department. In charge of the construction of full capacity aqueduct from Hunters brook in the Croton system

to Hill View reservoir on the northern limits of New York city and of the storage reservoirs and filtration work. Merritt H. Smith, and more recently F. E. Winsor, department engineer.

5 Long Island department. In charge of the development of the underground water supply of Long Island. A plan looking toward this end has been prepared and approved by the city authorities and is now being reviewed by the State Water Supply Commission.

6 City aqueduct division. In charge of the delivery of water from Hill View reservoir throughout Greater New York. Originally in charge of W. W. Brush, now under Walter E. Spear, as department engineer.

Departments are further divided into " divisions " each in charge of a division engineer and a full corps of assistants. The subdivisions of these larger units, although primarily based upon convenience and efficiency of engineering supervision, coincides rather closely with the larger geologic problems included in this bulletin.

Generalities of construction

The chief types of structure projected include (1) masonry dams, (2) earth dikes with core walls, (3) "cut and cover" aqueduct through country of about the elevation of hydraulic grade, (4) tunnels through mountains or ridges that are too high, and (5) pressure tunnels under valleys or gorges that are too low.

Some of these are of record proportions. For some of the details and figures *see* the different special problems in part 2.

All items complete as planned involve a total of:

10 dams
10 impounding, storage and distributing reservoirs
4.5 miles of dikes
54.5 miles of " cut and cover " aqueduct
13.9 miles of tunnel at grade
17.3 miles of pressure tunnel below grade
34 shafts of aggregate depth of 14,723 feet.
6.3 miles of steel pipes making
92.5 miles of aqueduct complete to Hill View equalizing reservoir
1 filtration works
18.0 miles of delivery tunnel in New York city to the terminal shafts in Brooklyn
16.3 miles of delivery pipe lines

Allowing for contingencies and costs for engineering supervision the system is estimated to cost $176,000,000 and many years will be required for its completion. The present plans, however, contemplate only the immediate development of the Esopus watershed, the storage reservoirs near the city and the main aqueduct to the various points of delivery within the city limits. It is expected that part of this additional supply of water will be available by the year 1913, or early in 1914.

CHAPTER II

PROBLEMS ENCOUNTERED IN THE PROJECT

When the Ashokan reservoir is filled the surface of the stored waters will stand 590 feet above the sea. Hill View reservoir on the northern borders of New York city will have an elevation of 295 feet. The distance between these two points is nearly 75 miles in direct line. The contour of the country and other exigencies of construction will increase this to approximately 92 miles. A main distributary conduit in New York city will add 18 miles more.

The destination of the water therefore before distribution begins is 300 feet lower than its starting point. This is sufficient head to permit gravitational flow and a self-delivering system. If the hydraulic gradient can be maintained it would evidently constitute a decided advantage. The plans have therefore from the beginning contemplated such construction. It means then that a flowing grade must be maintained in all tunnels or channels or tubes and that when a depression has to be crossed the pressure must be maintained in some sort of a conduit so that the water may rise again to a suitable level on the other side.

The difficulties of accomplishing this in a work of such magnitude are not at first apparent. The full significance of the undertaking can be realized only after a study of the country through which the aqueduct must be carried. It then resolves itself into a series of problems, each one having its own characteristics and peculiar difficulties and methods of solution and each requiring a thorough understanding of the topographic features of the vicinity and a working knowledge of geologic conditions.

General questions

It is sufficient at this point to call attention to the facts of the topographic map and point out only the most general physiographic features that may at once be seen to materially modify the simplicity of the line.

For example, one has scarcely left the great reservoir, with water flowing at 580–90 feet above tide, before the broad Rondout valley is reached, with a width of 4½ miles nowhere at great enough elevation to carry the aqueduct at grade. If it is to be crossed at all, and it must be crossed to reach New York city, some

special means must be devised. If a trestle be proposed, one finds that it would have to be 4½ miles long (24,000 feet), and in some places 300 feet high, and at all points large enough and strong enough to carry a stream of water capable of delivering 500,000,000 gallons daily — a stream that if confined in a tube of cylindrical form would have a diameter of about 15 feet.

A steel tube might be laid to carry the water across and deliver it again at flowing grade, but here one is met with the fact that it would require a tube of unprecedented size and strength and if divided into a number of smaller ones the cost would be greater than that of a tunnel in solid rock.

The other alternative is to make a tunnel deep enough in bed rock to lie beneath surface weaknesses and superficial gorges and in it carry the water under pressure to the opposite side of the valley. This is the plan that seems best suited to the magnitude of the undertaking and would seem to promise most permanent construction. But no sooner is this conclusion reached than it is realized that there are now several hitherto unregarded features that assume immediate and controlling importance. Some of these, for example, are (1) the possibility of old stream gorges that are buried beneath the soil, (2) the position of these old channels and their depth, (3) the kinds of rock in the valley, (4) their character for construction and permanence, (5) the possible interference of underground water circulation, (6) the possible excessive losses of water through porosity of strata, (7) the proper depth at which the tunnel should be placed, (8) the kinds of strata, and their respective amounts that will be cut at the chosen depth, (9) the position and character of the weak spots with an estimate of their influence on the practicability of the tunnel proposition. Then after these have all been considered the whole situation must be interpreted and translated into such practical engineering terms as whether or not the tunnel method is practicable, and at what point and at what depth it should cross the valley, and at what points still further exploration would add data of value in correcting estimates and governing construction and controlling contracts.

This is a general view of one case, the first one of any large proportions in following down the aqueduct. There are many others. In nearly all of them the importance of geologic questions is prominent. Many of them, of course, are of the simplest sort, but, on the other hand, some are among the most obscure and evasive problems of the science. And they do not become any

General view of the Rondout valley looking north along the aqueduct line from the margin of the Shawangunk range toward the Catskills. (Photograph by New York City Board of Water Supply)

easier simply to know that they must ultimately be stated in terms precise enough for the use of engineers, and to know furthermore that the real facts are to be laid bare when construction begins and as it progresses. But from another viewpoint it may be regarded as an exceptionally fine opportunity to study applied geology in its best form and to see the intimate interrelationship between an engineering enterprise of great public utility and a commonly considered more or less obscure science. The services of geology have been seldom so consistently employed in earlier undertakings of similar character. It is to be hoped that the accompanying illustrations of the practical application of geologic knowledge and facts to engineering plans and practice may add to the appreciation of the commonness and variety of such service in many everyday affairs. Furthermore, this unique enterprise, the like of which for magnitude and complexity has never before been attempted, has given to those whose good fortune has brought them into working relations with its problems, the opportunity of a generation in their chosen field.[1] The success stages from isolated observations, inference, hypothesis, theory, conclusions, and fully proven facts are all represented. The steps more or less fully coincide with the degree of confidence observable in the tone of advisory reports to the engineers in charge — representing suggestions, recommendations, or specific advice.

It is one of the cherished wishes of the writer of this bulletin that some of these problems may be presented in such manner as to serve a distinct educational purpose. For this reason in part, deeming it even of greater importance than the mere enumeration of newly discovered facts, the writer has chosen to treat the subject from the standpoint of an instructor illustrating the development of working conclusions. It is certain that not all readers have the same degree of preparation or acquaintance with the subject-matter, and it may therefore be useful to include many things that some may well pass by. No excuse is offered except that such method of treatment, in behalf of the general intelligent public that it is hoped to reach, seems to the author to be advisable.

[1] W. O. Crosby of the Massachusetts Institute of Technology, James F. Kemp and Charles P. Berkey of Columbia University have constituted the staff of consulting geologists throughout most of the exploratory work.

Other problems

The foregoing observations apply likewise to the other larger problems of the aqueduct line. A list of the larger ones requiring extensive exploration and illustrating geologic application in their solution are given below:

1 Location of the Ashokan dam
2 Sources of material for construction
3 Crossing the Rondout valley
4 The Wallkill valley
5 Moodna buried valley
6 Pagenstechers gorge and Storm King mountain
7 The Hudson river crossing problem
8 The Storm King-Break Neck cross section
9 Foundry brook
10 Sprout brook notch
11 Peekskill creek valley
12 Croton lake pressure tunnel
13 Bryn Mawr siphon
14 The new Kensico dam
15 Kensico quarries
16 New York city delivery tunnel

In addition to these there are several questions of general bearing in which the chief lines of argument and the chief basis of conclusion are essentially geologic. Although little wholly new data is yet available on these particular questions from any direct work of the aqueduct, yet it will add materially to an appreciation of the far-reaching influence of established geologic data and geologic reasoning to enumerate some of them:

17 Continental subsidence and elevation
18 Crustal warping
19 Postglacial and present faulting
20 Underground water circulation
21 Relative resistance of the different formations to corrosion by aqueduct waters
22 Structural materials

Each of these problems or questions or topics is discussed separately, so far as practicable. By adopting this plan, of course there is a tendency to repetition but this to a certain extent is unavoidable. Some of it is overcome by suitable references to preceding

discussions. Where such cross reference is too cumbersome, the items are repeated in preference to leaving the case obscure. Thus it is hoped to make each case a unit, and the whole series useful and understandable.

Gathering data

In the accumulation of data all the members of the engineering corps[1] as well as the men acting only in a consulting capacity have taken part. Necessarily the bulk of the exact data has been gathered by the men all the time on the ground and whose duty it was to superintend explorations. The care and intelligence with which this has been done is notable. A considerable proportion of the labor of manipulating the accumulated data and interpreting it so as to reach an explanation of conditions and formulate conclusions has been assumed by the consulting men.

Too much credit can not be given to the heads of departments and divisions for the open-handed way in which all needed facts were held available at all times for comparison and guidance toward sound conclusions. The information upon which investigations have been initiated have been chiefly the following:

1 The geologic maps and reports of the New York State Survey
2 United States topographic maps
3 Geologic folio no. 83, New York city folio
4 Earlier engineering records and reports
5 Reports of special commissions on water supply

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[1] In this work, no group of men have had so direct responsibility as the division engineers. The success with which so many complicated explorations were carried out is chiefly due to their constant care and foresight and perseverance and the able assistance of their staff. Those who have had especially important divisions for the geological problems involved are given due credit in the discussions of part 2, of this bulletin. It is easy, however, to neglect sufficiently full acknowledgment of their services in gathering and formulating data of this kind. Among those having charge of the most important exploratory work the following names should appear:

James F. Sanborn, for sometime assigned to geologic work on the Northern aqueduct.

William E. Swift, in charge of the Hudson river explorations..

William W. Brush, in charge of the early New York city explorations.

Lazarus White, in charge of the Rondout valley explorations.

Lawrence C. Brink, in charge of the Wallkill division explorations.

J. S. Langthorn, in charge of the exploratory work at the Ashokan Reservoir.

Wilson Fitch Smith, in charge of work at Kensico dam, and

A. A. Sproul, in charge of the Peekskill creek and Sprout brook explorations.

Some of these are printed reports and records not directly concerned with this enterprise, but whose information has been found useful in this field. This is especially true of the first four sources enumerated, 1, 2, 3, 4. The last is a specific study with direct reference to this project.

Investigations were begun from the above vantage point. The methods employed and the explorations conducted constituting the further sources of information and furnishing the complete data upon which all conclusions have been based include the following:

6 Detailed topographic studies of the engineers of the Board of Water Supply
7 Geologic field work making observations in detail of all geologic factors that seem to bear on the problem in hand
8 Wash borings for depth to bed rock
9 Chop drill holes through stony ground to bed rock
10 Shot drill holes in bed rock
11 Diamond drill holes
12 Test pits and trenches for detail of drift structure
13 Test tunnels in rock for working quality
14 Deflection tests for holes that have swerved aside
15 Pumping tests for underground water supply
16 Pressure tests for rock porosity
17 Microscopic examinations of rock types
18 Laboratory tests of quality and behavior of materials.

The mass of data accumulated from all these sources is surprising. For example, there are upward of 200 wash borings on the different proposed Hudson river crossing lines alone; there are 69 drill borings and 177 wash borings on the site of Kensico dam; there are 69 shot and diamond drill holes on the Rondout siphon line aggregating 10,234 feet of rock core; there are 65 drill holes of various sorts on the Moodna creek siphon aggregating in total penetration of drift over 10,000 feet; there are 106 borings, besides several pits and trenches at Ashokan dam location. At every point explorations suitable to the particular problems in hand were conducted. The whole mass of data is conveniently recorded, much of it is tabulated, some of it is represented graphically, samples of nearly all of the material are available for examination,[1] and all

[1] The cores of all drillings and suitable samples of all borings in drift have been saved and properly labeled and are to be permanently housed at some convenient point on the aqueduct line when completed. At present they are cared for at the different division offices.

have been made use of in coming to a consistent understanding of the conditions.

But the amount of accumulated data is no more remarkable than the difficulties that have been encountered in obtaining it. For example, in the Moodna valley it has taken three to four months' time to put down a single hole to bed rock — the average time consumed for each of the 15 holes exploring the deepest portion of the valley was about 60 days. The chief trouble is caused by heavy bouldery till. In one case a boulder was penetrated for 35 feet. lying a hundred feet above bed rock.

The extreme of such difficulty is, of course, encountered in the Hudson river itself, where the drill has to contend with: (1) the rise and fall of the tides, (2) the river currents, (3) a maximum of 90 feet of water, approximately 700 feet of silt, gravel, till, boulders, etc., filling the old preglacial gorge. The heavy steamboat and towing traffic has been a serious element in the problem. Probably never anywhere have drillmen had to face so nearly insurmountable obstacles. In two years only two holes reached below a depth of 600 feet below sea level. A third, now in progress, has penetrated a depth of 768 feet without entering rock.

CHAPTER III

RELATIVE VALUES OF DIFFERENT SOURCES OF INFORMATION AND STAGES OF DEVELOPMENT

In the earlier stages of work topographic features were of most concern, and they largely controlled the selection of reservoir sites and possible lines for the aqueduct to follow. It was, however, at once recognized that tunnels would be unavoidable and studies as to the types of rock formations to be encountered were begun It was also early appreciated that the soil or drift cover is very unevenly distributed over the rock surface and that, especially in the chief valleys requiring pressure tunnels, it would be necessary to determine the profile of the rock floor. At this point wash borings were begun. But the natural limitations of the wash rig[1] for penetrating drift of all kinds left the information still too indefinite. The wash rig can not penetrate hard rock. It can not wash up anything but the finer matter, and a boulder of very moderate size is almost as effectual a barrier as true rock ledge. By a combination of washing and chopping or by the use of an explosive to break or dislodge an obstruction some progress in unfavorable material may be made, but the wash rig alone, in a drift-covered region, gives only negative results. It is certain, for example, that bed rock lies at least as deep as the wash rig has penetrated, but it is not certain that it is bed rock instead of some other obstruction. Except in areas of special drift conditions,[2] therefore, the wash rig was insufficient. To rely upon the process at random was clearly impossible, and to determine whether or not the results of a particular locality

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[1] A "wash rig" is a device composed essentially of two iron pipes, one within the other, and so mounted that the inner one can be worked up and down in sort of a churning fashion while water under considerable pressure is forced through it to the bottom and out again by the larger pipe to the surface, carrying up with the current the displaced sand and clay. As progress is made with the inner pipe the outer one is from time to time driven down and the process renewed and repeated till the hole is finished.

[2] One of the most notable areas of special drift conditions is represented in the Walkhill valley [*see* discussion in pt 2] where there were developed large deposits of modified drift, stratified gravel, sand and clays, lying immediately upon the bed rock floor. In this the wash bore process was eminently satisfactory, and the rapid progress made by it together with its economy made this an especially attractive method of exploration.

could be relied upon became involved at once with an interpretation of local glacial phenomena, especially an interpretation of the character of the local drift. In order to see the limited application of this method one needs only to point out that the majority of drift deposits in this region are stony or even bouldery, forming thick coverings in the valleys, and to call attention to the experience at two or three points. For example, at Moodna creek, the preliminary wash borings were obstructed and bed rock reported at 5 to 15 feet below the surface where afterward, by other means, it was proven to lie more than 300 feet down. Or again, in the preliminary wash borings in the Hudson, the rigs were stopped and rock bottom provisionally reported at from 25 to 200 feet below sea level, but later explorations have proven at the same point that rock bottom is more than 700 feet down.

Therefore, to the "wash rig" was added the "chop drill" and the "oil-well rig" and to these, or to modifications of them,[1] the success in reaching bed rock has been due.

From independent field studies of a more strictly geologic nature it became clear that many of the valleys, where pressure tunnels were proposed, are of comparatively complex geologic structure and exhibit considerable variety of rock quality and condition. This then introduced and necessitated still more elaborate lines of exploration. It was not enough to know the profile of rock floor alone, it became of equal importance to penetrate the rock and obtain samples of it. So the shot drill[2] and the diamond drill[3] were employed and the drill cores preserved for identification and reference.

[1] The essential features of the machines in most instances are, a high tower or support, a heavy chisel-shaped plunger that can be raised by a rope and dropped repeatedly in the hole, destroying or displacing obstructions, and which can be followed by a casing driven down as progress is made — a combination of washing, chopping and driving.

[2] The shot drill, or calyx drill, is essentially a machine devised to rotate a steel tube which is so adjusted and manipulated that a supply of small chilled shot can be kept continually under the lower end as it bores into the rock. The cutting is done by the shot immediately under the edge of the tube. A core remains in the tube and may be recovered. Its best position is vertical.

[3] The diamond drill consists essentially of a bit or crown set with black diamonds (bort) in such manner that when the bit is attached to a rotating tube a circular groove is cut into the rock. By proper attachment to jointed tubes and driving gear a hole may thus be bored at any angle and to great depth and a core recovered.

These preserved cores, now aggregating many thousands of feet have been of great service in determining the precise limits of formations and consequently the geologic structure or cross section, by which detailed estimates may be guided.

Even these occasionally appeared to give insufficient data. The peculiar behavior of certain holes, as, for example, one or more at Foundry brook,[1] led to the suspicion that the drill had swerved from its course, following a particularly soft seam or zone, and that the results secured by it without large corrections, were wholly misleading. Tests proved that there had been a deflection.

At this and many other places it later became very desirable to form some quantitative as well as qualitative opinion of the conditions existing in the underlying strata. The percentage of core saved, the rate of progress of the drill, the behavior of the drill, the condition of the core recovered, the loss of water in the hole — all these of course were considered.

For more definite evidence as to porosity and perviousness, a series of carefully planned pressure tests[2] were made. By shutting off connection with the walls of the hole above a certain stratum and forcing water in under pressure, it was possible to demonstrate that certain strata or certain portions were practically impervious in their natural bed, while others were much less so, and to get an idea of their relative efficiency as water carriers. For the pressure tunnels, especially, this test is a very suggestive line of investigation.

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[1] At Foundry brook [*see* discussion of this problem in pt 2], the remarkable condition apparently shown was a reasonably substantial ledge of granitic gneiss, 50 feet, followed below by 200 feet of apparently soft sand and reported as such. No core could be recovered. So extensive a zone or bed or layer or mass is hardly conceivable considering the crystalline silicious character of the rock. It probably represents a steeply dipping crush zone along fault movement where the increased underground circulation has been unusually effective in producing decay. After entering this zone the drill swerved from its initial course and kept within the soft seam.

[2] The pressure test is made by means of a force pump, fitted with a gage on which the pressure is recorded, connected by a pipe to the portion of the hole to be tested, and so adjusted to a device for blockading or damming the hole that the water pressure is confined to those portions of the walls of the hole below the dam, or between two dams if an upper and lower one are used. In this way any portion of a hole, or stratum or several beds together may be tested and the amount of water absorbed per unit of time per unit of pressure determined. This is, of course, directly related to the porosity of the rock and is approximately inversely proportional to its presumed value as an aqueduct carrier.

Where the strata are especially porous and where underground or permanent ground water supplies are very extensive and where at the same time the largest or deepest pressure tunnels are projected some uneasiness has been entertained as to the extent of interference from inflowing water during construction. An attempt to form some idea of the ease of such underground circulation has been made by a systematic pumping of one or two critical holes. The results leave many factors still too obscure to draw definite conclusions. The test will be taken up again in the discussion of the Rondout siphon in part 2.

Laboratory tests and experiments on materials complete the list of lines of investigation with which this bulletin is concerned. Although from the nature of the case these are elaborate and unusually complete, the more important lines are not at all new. All the methods of petrographic, chemical, and physical manipulation that seem to promise practical results of value to the success of the undertaking are followed and the data are organized and interpreted and conclusions are formulated with as great definiteness for practical bearing as other lines of investigation.

CHAPTER IV

GENERAL GEOLOGY OF THE REGION

It will save much repetition and it is believed will altogether serve a useful purpose in maintaining unity of treatment to give an outline of the geologic features of the region in advance of the discussion of special problems. It is intended only for those not sufficiently familiar with the general geology to follow subsequent matters.

The region includes some of the most complicated and obscure sections of New York geology. It is simple in almost no one of the larger branches of the subject. In physiography there is the long and involved history and the results of long continued erosion of a variable series of formations in different stages of modification as to structure and metamorphism and attitude, modified still further by subsidences and elevations, depositions and denudations, peneplanations and rejuvenations, glaciation and recent erosion — all together introducing as much complexity as can well be found in a single area.

In stratigraphy the whole range of the eastern New York geologic column is represented from the oldest known formation up to and including the Middle Devonic — a succession of at least 25 distinct formations which may for convenience be treated in groups that have had similar history. Each of these formations has a constant enough character to map and regard as a physical unit. Even this classification ignores the great range of petrographic variability shown in such formations as the Highlands or Fordham gneisses. All but two or three of these formations will be cut by the tunnels of the aqueduct.

In petrography the range is even greater — so great, in fact, that only an enumeration of the variations will be attempted. They include clastics, metamorphics and igneous types; stratified and unassorted, coarse and fine, detrital and organic, marine and fresh water, homogeneous and heterogeneous, argillaceous, calcareous and silicious sediments, unmodified and thoroughly recrystallized strata; acid and basic and intermediate intrusions; massive and foliated crystallines — of many varieties or variations in each group.

In tectonic geology an equal complexity prevails. There are regular stratifications, cross-beddings, disconformities, overlaps and unconformities; interbeddings, lenses and wedges; flat, warped, tilted

and crumpled strata; monoclinal and isoclinal, open and closed, anticlinal and synclinal, symmetrical and overturned, horizontal and pitching folds; joints, crevices, caves, crush zones, shear zones, and contacts; normal, thrust, dip, strike, large and small faults; veins, segregations, inclusions, dikes, sills, bosses and bysmaliths.

With such variety of natural conditions it is not surprising that the problems of the aqueduct are also of great variety. No two have in all respects the same factors in control and no two can be explored and interpreted upon exactly the same lines.

1 Geographic features or districts. (Physical geography[1])

It will be convenient at this point to think of the surface topography by districts — not wholly distinct from each other, but still with essential differences of origin and form. From south to north they are: (*a*) New York-Westchester county district. The area of crystalline sediments. South of the Highlands. (*b*) Highlands of the Hudson (Putnam county). (*c*) Wallkill-Newburgh district. From the Highlands to the Shawangunk range. (*d*) Shawangunk range and Rondout valley. (*e*) Southern Catskills.

All have been sculptured by the same forces and with similar vicissitudes, but the difference of history and structure and condition, already established when the physiographic forces began on the work now seen, have caused the variety of surface features indicated in the divisions made above. The more noticeable characteristics of these five districts are here given.

a **New York-Westchester district.** The area south of the Highlands proper is characterized by a comparatively regular succession of nearly parallel ridges separated by valleys of nearly equal extent (½ to 5 miles wide), making a surface of gently fluted aspect and of moderate relief (0–500 feet) sloping endwise toward the Hudson and the sea. The controlling factors in producing this topography are involved in a series of folded, foliated, crystalline sediments, of differing resistance to destructive agencies.

b **The Highland region** is one of rugged features, with a range of elevation of 0–1600 feet A. T., forming mountain masses and ridges separated by very narrow valleys all having a general northeast and southwest trend across which the Hudson cuts its way in a narrow, angular gorge, forming the most constricted and crooked portion of its lower course. The bed rock is all crystalline,

[1] The physiographic history of a region is not understandable without a comprehensive knowledge of its geologic features and structures and history. It is therefore treated in a later paragraph.

View looking west from Sky Top in the Shawangunk range with Mohonk lake in the foreground and the Rondout valley in the distance with the Catskills in the background. (Photograph by the Board of Water Supply)

of massive and foliated types, metamorphosed sediments in part with large masses of igneous intrusions and bosses.

c **The Wallkill-Newburgh district** lying immediately north of the Highlands and extending to the Shawangunk range is a region of gently rolling contour. Most of the area along the proposed lines lies between 200 and 500 feet above the sea. There are only occasional rugged hills or short ridges, such as Snake hill and Skunnemunk. The valleys are broad and smooth and the divides are simply broad, hilly uplands. Bed rock is chiefly Hudson River slates with occasional belts of Wappinger limestone. The larger features, the trend of divides and valleys, are northeast and southwest, although this regularity is not so marked as in the preceding two districts. But the chief streams flow either northeast or southwest to the Hudson along these general lines.

d **The Shawangunk range and Rondout valley** form a transitional unit from the complicated structural and tectonic conditions of the southerly districts to the uniform and almost undisturbed strata of the Catskills. Its southeasterly half is a mountain ridge partaking of extensive faulting and folding and represented by the Hudson River slates overlain unconformably by the thick and very resistant Shawangunk conglomerate forming high eastward-facing cliffs. Toward the northwest these disturbances diminish, the strata gradually pass deeper beneath a great succession of shales, limestones, and sandstones of the Helderbergian series, and a broad valley is eroded in the softer portions. It is limited on the northwest by the prominent and very persistent escarpment bordering the Hamilton series and forming the outer margin of the Catskill mountains.

e **The Catskill area** is of simple structure. The strata are well bedded and lie almost flat with a gentle dip northwest. The surface features form a series of irregularly distributed escarpments, hills, valleys, cliffs, gorges and mountains, rising rapidly toward the west, with moderate to strong relief and reaching elevations of 2500 feet. The failure of the northeast-southwest trend of feature that is so common in all of the other districts is a marked difference. It is directly due to the flatness of the strata.

2 Stratigraphy

There are no strata of prominence in association with the main aqueduct younger than Devonic age except the glacial drift. Immediately adjacent areas, however, some of which are covered by the accompanying maps, and Long Island have later formations ex-

tensively developed. Such are the Triassic rocks of the New Jersey side of the Hudson below the Highlands, and the Cretaceous and Tertiary strata of the Atlantic margin on Long Island and Staten Island. The development of underground water supply on Long Island is especially concerned with these later formations, and with the modified drift deposits of the continental margin.

The whole series of formations are more commonly considered in groups that exhibit certain age or physical unity and that are for the most part characteristic of certain regional belts and that coincide somewhat roughly with the physiographic divisions already noted. There is in the following description and tabulation no direct attempt to unduly emphasize this relation or to belittle the divisions recognized in the commonly adopted geologic column. It is, however, for the purpose in hand, more convenient and useful to keep clear the physical groupings, because largely these groups, instead of the more arbitrary subdivisions of age, are the units used in considering structural and applied problems.

a **Quaternary deposits.** (1) *Glacial drift.* A loose mantle of soil and mixed rock matter covers the bed rock throughout the whole region except (*a*) here and there where the rock sticks up through (outcrops), and (*b*) at the most southerly margin along the coast where the glaciers seem not to have reached.

Origin. This mantle is usually very different in lithologic character from the underlying rock floor. There is almost always an abrupt break between the rock floor and the overlying material. The rock floor is grooved, smoothed, and scratched as if by the moving of rock or gravel over it. The larger boulders are usually of types of rock identical with ledges lying northward at greater or less distance. Materials of exceedingly great variety both in size and condition and lithologic character are often all piled together in the most hopelessly heterogeneous manner. These are now commonly regarded as conclusive evidence of glacial origin. There is no need of making the discussion exhaustive. It is almost universally called the "*drift.*"

Thickness. The thickness of the drift varies from almost 0 to approximately 500 feet. It is generally thickest in the valleys where it has simply filled many of the original depressions and obliterated much of the ruggedness of surface, the gorges and ravines and canyons of the preglacial time.

Sources. It appears from an examination of the grooves and striae on bed rock, and the relationship of the different types of drift to each other, and from a comparison of the types of boulders

with the ledges that may be regarded as their source, that the general ice movement was from north to south swerving along the southerly extension to east of south. Therefore it is not unusual to find abundant boulders of Palisade trap stranded in New York city or on Long Island, or boulders of the Cortlandt series, or of the gneisses of the Highlands, or, in occasional instances, of sand stones from the Catskills, or the limestones from the Helderbergs or perhaps in rarer cases even rocks from greater distance, as the Adirondack mountains.

Kinds of drift. There are in the region two fundamentally different types of drift as to method of deposition. They are (*a*) unassorted drift (till or hardpan), and (*b*) modified drift (stratified or partially assorted gravels, sands, clay, etc.). The former (*a*) represents deposition directly from the ice sheet at its margin (terminal or marginal moraines) or beneath ("ground moraine") without enough water action to rework and assort the material. It therefore contains boulders, pebbles, sand and clay of a heterogeneous mixture of the most complex sort both as to size and character. In such deposits there is almost always sufficient intermixture of clay and rock flour of the finest sort to make a very compact and dense mass that is usually quite impervious to water. Such deposits are distributed rather unevenly over the surface and where this unevenness leaves hollows or basins, or obstructs the outlets of other depressions, they may hold water and form small lakes or ponds or swamps. This is almost universally the origin of the many thousands of lakes of the northern lake region. It is evident that material of this character, a type that commonly serves the purpose of a natural dam or reservoir, would be especially important and useful at certain places on the Catskill system. As a matter of fact, so far as geologic features are concerned, it is the chief factor in choice of location for the Ashokan dam [*see* discussion pt 2] and is a controlling factor in the plans for the erection of the miles of dikes at less critical margins of the reservoirs. Till is an extensively developed type but frequently passes abruptly either laterally or vertically into assorted materials of very different physical character.

(*b*) All materials associated in origin with the glacial occupation that have been materially modified especially in the direction of an assorting of material are referred to as "modified drift" deposits. They include (1) deposits made by both water and ice together, (2) those formed by running water, (3) those laid down in stand-

ing water. Or again (1) those accumulated rapidly with very irregular supply of material at the margin of the ice-forming, hummocky or hill and kettle surface (kames, eskers), (2) those carried along valleys or general lines of drainage to a considerable distance beyond the ice margin aggrading the valley with the overload of gravels and sands (valley trains), (3) those washed out from the ice margin in more even distribution forming a gently sloping and thinning extramarginal fringe (outwash or apron plains), (4) those fine matters that are carried by glacial streams into the margins of more quiet waters, either a temporary or a permanent lake or a larger and slower stream or other body forming more perfectly assorted and more evenly stratified deposits (delta deposits), (5) those finer rock flours and clays that remain suspended longer and carry out much farther settling only in the very quiet waters of lakes or estuaries or temporary water bodies of this character forming the perfectly banded clays (glacial lacustrine clays).

It is evident then that modified drift has in the process of its accumulation suffered chiefly a separation of fine from the coarse particles and that in most cases the fine clay filling that makes the till dense and impervious to water, has been washed out and deposited by itself in the more inaccessible deeper waters. As a result most modified drift deposits are pervious and easy water conductors, but poor or questionable ground for dikes or dams or basins [*see* discussion of Ashokan dam, pt 2].

Some of them, the medium sands and gravels, furnish an excellent and already cleaned structural material for concrete or mortar, such as the Horton sand deposit, or coarser kinds may be crushed and sized before using as is done at Jones Point on the Hudson.

The finer silts and clays, usually overlain by assorted sands, are abundant along the Hudson, having been deposited there at a time when the water of this estuary stood 50 to 150 feet higher than now. Recent erosive activity of the river has cut the greater proportion of the original deposits away but at many places large quantities still remain above water level in the banks and still greater quantities extend beneath the river. These deposits are the support of the brick industry of southeastern New York. The till deposits are very difficult to penetrate in making borings because of the boulders, the wash rig being almost useless. Modified drift of the medium and finer sorts is easily and cheaply penetrated, and, if it lies on bed rock, such exploration gives reliable results.

Structure. But this is stating the actual conditions too simply. The glacial epoch was a complex one The continental ice sheet may

have advanced and retreated repeatedly, how many times in this region is not clear. With each time of advance and retreat, the work done by it partly destroyed, or disturbed or modified or covered the earlier ones in what appears now to be a most arbitrary way (in reality, of course, in a very consistent way for the conditions that then existed). So one frequently finds a till beneath a deposit of stratified drift, or modified drift beneath till, or a succession of a still greater number of changes in almost hopeless confusion. In New York city, for example, at Manhattanville cross valley, the exposed drift above street level includes (*a*) at the bottom, water-marked stony till and assorted gravels, (*b*) in the middle perfectly horizontal, stratified rock flour and the finest sand, (*c*) top, wholly unassorted bouldery till, covered by thin soil. It is evident that the most careful and accurate identification of the surface type without subsurface investigation would give, for such uses as are now being considered, thoroughly unreliable evidence as to the behavior of the whole body at this point. Therefore, a determination of the changes and quality forms an essential record. All of these types are to be found in the region, but the different grades of till and roughly modified material belonging to the kame type are more common inland.

On Long Island the development of marginal modified types is extensive and more or less obscured by the advance and retreat noted above. The larger divisions recognized in deposits are (*a*) an early accumulation of sands and gravels, strongly developed near the western end of the island, known as the "Jameco" gravel, (*b*) an interglacial (retreatal) deposit of blue clays known as the "Sankaty" beds, (*c*) a later series of deposits, sands, clays, gravels and till, belonging to the closing stages of the ice period corresponding to the surface deposits of the larger portion of the whole region (Tisbury and Wisconsin advances). Some of these sands and gravels are important water-bearing sources for the new Brooklyn additional supply.

The whole Long Island series according to Veatch[1] includes:

Wisconsin stage	Glacial two lines of terminal moraines with outwash plains	Harbor hill moraine Ronkonkoma moraine
Tisbury stage	Great deposit of outwash sand and gravel (depression) Gardiner interval with erosion (interglacial)	

[1] After PP 44, U. S. Geological Survey, p. 33.

Gay Head	Folding (glacial folding) Sankaty retreatal stage (interglacial) clay beds
Jameco	Glacial — Jameco gravels Postmannetto erosion (interglacial)
Mannetto stage	Glacial — old gravels

A radically different and in some respects a much simpler interpretation[1] of the Long Island deposits has been outlined by W. O. Crosby. The essential feature of his classification is the unity and simplicity of the glacial epoch. Only the moraines and associated sands and gravels of outwash origin during advance and retreat are regarded as glacial. All other deposits below and including the Sankaty clay beds he regards as preglacial.

The Jameco gravels are interpreted as Miocene in age.

Certain persistent yellow gravels overlying the Jameco are classified as Pliocene.

b **Tertiary and Cretaceous deposits.** (2) *Tertiary outliers.* Deposits of *Pliocene* age are littoral in type [PP 44 U. S. G. S. p. 28] and are not very well differentiated (Long Island, Staten Island). Probably equivalent to the *Bridgeton* beds of New Jersey.

Certain "fluffy" sands in thin beds are assigned by Mr Veatch to the *Miocene* (Long Island, Staten Island). Probably equivalent to the *Beacon hill* deposits of New Jersey. Crosby places the Jameco gravels in the Miocene together with the Kirkwood lignitic and pyritic clays and sands.

(3) *Upper Cretaceous* deposity[2] are extensively developed. They form the chief bed rock of Long Island.

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[1] The writer offers both of these outlines of the glacial and associated deposits in preference to either alone. Both Veatch and Crosby have given immensely more time to the study of these questions than any one else. It is hardly fitting for a newcomer in their field to reject either view. But because of the very great difference between the two interpretations one may be pardoned a preference. It is the writer's opinion that the simpler outline is the more tenable. It does not seem possible to establish a very complex series of stages in the glacial epoch as represented in the deposits of southeastern New York.

[2] Crosby's classification of the Cretaceous is as follows:

(*a*) Monmouth — slight development of marls. (Lower and middle marl series.)

(*b*) Matawan — (clay marl series) probably present on Long Island.

(*c*) Magothy — an extensive series of variegated and micaceous sands and clays. Heavy development on Long Island.

(*d*) Raritan — Plastic clay scales and the Lloyd sand.

(*a*) A lignitiferous sand with occasional clay beds forming the *uppermost* of the *Cretaceous* series is probably equivalent to the *marl* series of New Jersey. But it lacks the prominent greens and development characteristic of the region further south. Not clearly separable from the underlying formation or Matawan beds.

(*b*) The Matawan beds. Gray sands and clays.

(*c*) Raritan formation. Clays and sands, plastic clays, the *Lloyd sand,* an important water carrier lies about 200 feet below the top of the formation. Occasional leaf impressions.

All of these formations, except where disturbed locally by glacial ice, dip gently seaward. The sand beds of these strata are the chief sources of underground water being developed by the new system.

c **Jura-Trias formations.** (4) *Palisade diabase.* This is a thick intrusive sheet, or sill, of igneous rock of diabasic type. It is 700–1000 feet thick. It lies for the most part parallel to the bedding of the surrounding, inclosing, sedimentary rocks, and, rising gently eastward, forms a strong cliff continuously along the west bank of the Hudson for 40 miles. It varies from very fine to very coarse texture and is for the most part fresh, tough, durable, and is the source of large quantities of the most satisfactory quality of crushed stone now on the market for use in concrete.

(5) *Newark series.* This is a very great thickness of silicious sediments, chiefly reddish conglomerates, red and brown quartzose and feldspathic sandstones and shales. They dip gently westward and northwestward at 10–20 degrees, and are confined, in this region, to the west side of the Hudson south of the Highlands. The formation supplies " brownstone " for building purposes.

None of the Jura-Trias rocks, so far as known, will be cut by the aqueduct.

d **Devonic strata.** (6) *Catskill formation.* This formation[1] is of continental type, chiefly a conglomerate. A white conglomeratic sandstone forming the uppermost portion attains its greatest thickness on Slide mountain (350 feet). It is a " coarse grained, heavy bedded, moderately hard sandstone containing disseminated pebbles of quartz or light colored quartzite, and streaks of conglomerate."

A red conglomeratic sandstone constitutes the much thicker portion below (1375 feet). It is a " coarse, heavy bedded sandstone of dull brownish hue containing disseminated pebbles and conglomeratic streaks, differing from the overlying beds chiefly in color. In

[1] Grabau, A. W. N. Y. State Mus. Bul. 92. Geology and Paleontology of the Schoharie Valley.

both series the pebbles and conglomeratic streaks are scattered and irregular, while the sands are often cross-bedded. Thin layers of red shale occur, and locally gray sandstones." The deposits probably represent flood plains, deltas, and alluvial fans accumulated mostly above sea level.

(7) *Oneonta sandstone* (Upper flagstone). "Thin and thick bedded sandstones from 20 to 200 feet thick with interbedded red shales up to 30 feet thick." Chiefly light gray to brown in color. Abundant cross-bedding, occasional dark shale, frequent flagstone beds. Capable of furnishing "bluestone" flags and more massive dimension stone. To be seen in the vicinity of West Shokan and westward.

(8) *Ithaca and Sherburne* (lower flagstone "bluestone"). "Thin bedded sandstone, with intercalated beds of dark shale. The sandstones are in masses from a few inches to 40 feet in thickness, greenish gray to light bluish gray or dark gray in color, and are extensively quarried as flagstones." There are occasional conglomeratic streaks. Occurs in large development in the vicinity of the Ashokan reservoir (500 feet). The heavier cross-bedded and coarser grained beds are capable of furnishing an unusually good quality of large dimension stone for heavy structural uses. The beds of this formation near Olive Bridge will in all probability furnish the greater proportion of stone of all kinds for the construction of the great Ashokan dam [*see* discussion of bluestone near Ashokan dam, pt 2]. The chief common fossil content is impressions of plant remains.

(9) *Hamilton and Marcellus shales.* "Dark gray to black or brown shales with thin arenaceous beds in the upper part." Forms the upper portion of the escarpment that follows the outer margin of the Catskill foothills bordering the westerly side of the middle Rondout and lower Esopus valleys. Occasionally beds are substantial enough for flagstone production (700 feet or more with the Marcellus.)

The chief index fossils are: Spirifer mucronatus, Athyris spiriferoides, Chonetes coronatus.

The Marcellus shale is not readily differentiated in the Esopus valley. Characteristically it is a thin bedded shale of no great thickness (180 feet in the Schoharie valley) lying between the Onondaga limestone and the Hamilton and obscured by talus from the escarpment (with the Hamilton 700 feet.)

Styliolina fissurella, Chonetes mucronatus, Strophalosia truncata, Liorhynchus mysia.

The Sherburne flags at Olive Bridge. (Photograph by Board of Water Supply)

The dividing lines between the different sandstones and shale formations, the Oneonta, Ithaca, Sherburne, Hamilton and Marcellus, can not be sharply drawn in the Esopus region. Together they form in a large way a rather satisfactory field unit. For specific purposes it is necessary to recognize that the lower portions are prevailingly shales with thin bedded sandstones while the upper portions are much more heavily bedded, the sandstones pre-

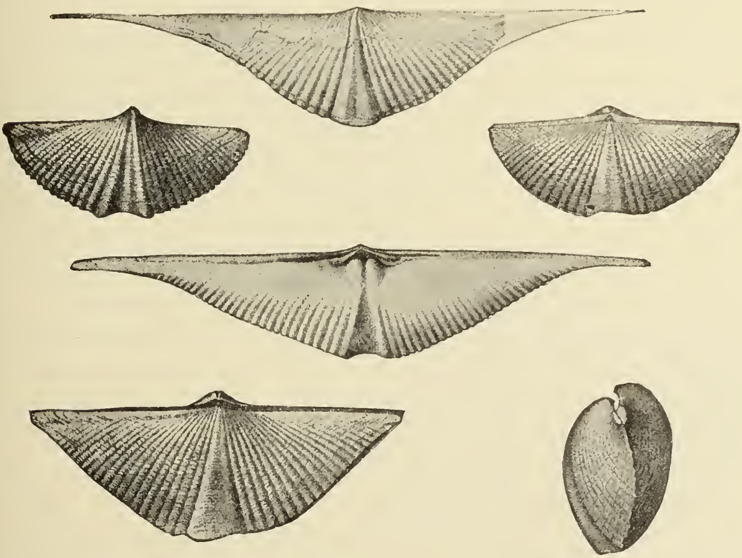


Fig. 2 Spirifer mucronatus (Conrad), a characteristic and abundant index fossil of the Hamilton shales of the Catskill margin

vailing. The five divisions may possibly be more satisfactorily made on paleontologic characters than on physical, but in most of the advisory reports on economic and practical problems involving this district the subdivisions can not be emphasized. The whole series is essentially conformable and is very little disturbed [*see* report on bluestone quarries, pt 2].

(10) *Onondaga limestone.* A bluish gray, massive, thick bedded cherty, somewhat crystalline limestone. It is strongly marked off from the Hamilton and Marcellus above, and, because of its greater resistance to erosion, usually forms a dip slope controlling stream adjustment and ultimately inducing the development of unsymmetrical valleys with gentle easterly slopes and clifflike westerly borders where the streams are sapping the overlying Marcellus and Hamilton shales. It is not sharply separable from the Esopus below but everywhere in this region graduates into it with increase of silicious

and argillaceous impurities. Estimating the formation from the drill cores that have penetrated it, and placing the lower limit as nearly as may be at the horizon of changes from predominant lime to predominant silicious content, the approximate thickness in this region is placed at 200 feet. The rock where exposed exhibits considerable joint development and these are considerably enlarged by the solvent action of percolating waters. This factor is considered of some importance in connection with the other limestones of the district in aqueduct construction and permanence. The Onondaga has been used as a building stone formerly sold as marble, some grades of which are good stone. On the line of the aqueduct it is confined to the Rondout and Esopus valleys. The chief fossils are: Atrypa reticularis, Zaphrentis prolifica, Leptostrophia perplana, Platyceras dumosum, Leptaena rhomboidalis, Dalmanites selenurus.

(11) *Esopus and Schoharie shales* (a slaty grit). The Schoharie as a distinct formation is not distinguishable in this region. The very thick and comparatively uniform, gritty, black, dense, almost structureless rock is a distinct unit. It is a silicious mud rock with very obscure sedimentation markings, but showing independent secondary cleavages induced by later dynamic factors, and, on long exposed surfaces always exhibiting chiplike fragments as the result of weathering. But it is not an easily destroyed rock. In so far as the bedding is obscure and the induced structure predominates, the rock is a slate; and in so far as it is distinctly gritty (sandy) instead of argillaceous it is a grit. The formation might therefore be more accurately designated as a slaty grit. The lack of plain bedding structure makes it impossible to estimate its thickness, since the foldings or other displacements can not be allowed for; but the accumulated data of drill holes in more advantageous position indicate an approximate thickness of 800 feet. The rock is considered exceptionally good ground for the tunnel.

A few fossils occur the most characteristic being Taonurus caudagalli. There are also in certain layers of limited extent, Leptocoelia acutiplicata and Atrypa spinosa.

(12) *Oriskany and Port Ewen transition* (silicious shaly limestone). There is no well defined and distinct separation here between the Oriskany and the underlying Port Ewen, but because of the importance and persistence of the formation in other and related areas the name is held. The equivalent of the Oriskany is in this district involved with a strongly developed transition zone which in physical features is intimately associated with the Port

Ewen as a single unit. If any distinct formation is to be recognized it would be on the basis of transitional faunal character, placing the fossiliferous upper 100 feet in the Oriskany transition and confining the name Port Ewen to the rather unfossiliferous and concretionary, shaly, argillaceous limestone of the lower 100 feet.

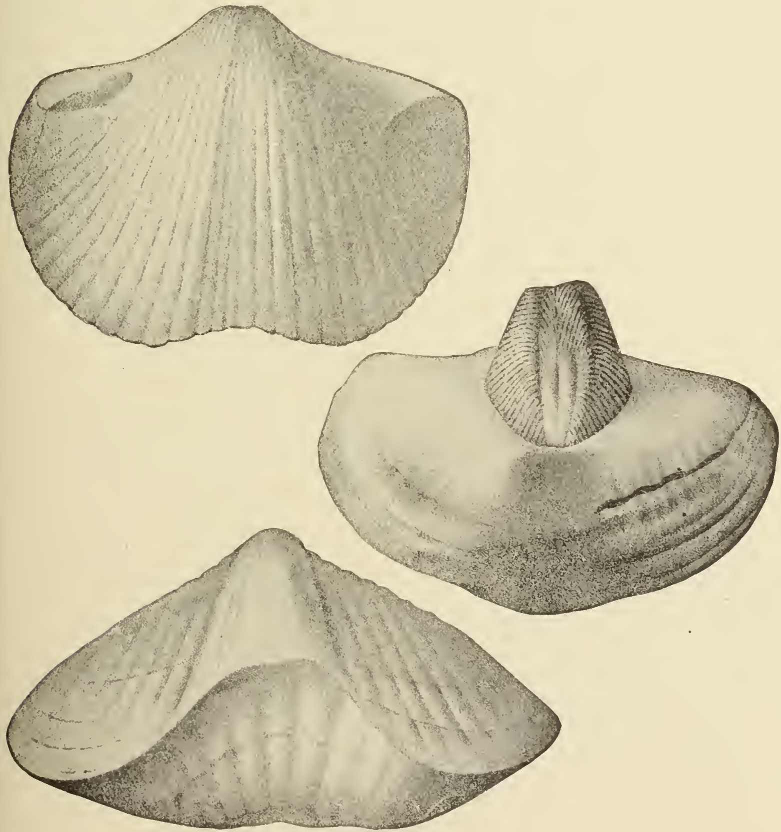


Fig. 3 Spirifer arenosus (Conrad), one of the characteristic index fossils of the Oriskany occurring in the Port Ewen-Oriskany transition

This transition rock is strongly bedded, argillaceous and silicious limestone, very quartzose in certain layers, but there are no exposures in this area that would be called sandstones. Fossils are abundant and show marked Oriskany peculiarities. Those of most characteristic relations are: Hipparionyx proximus, Leptostrophia magnifica, Spirifer murchisoni, Spirifer arenosus, Platyceras nodosum, Strophostylus expansus.

(13) *Port Ewen shaly limestone.* The beds below those noted in the preceding paragraph are essentially argillaceous, shaly limestones. They vary from rather massive to thin bedded, are dark grayish in color, and have a peculiar nodular or concretionary development along certain sedimentation lines. These spots have less resistance to weather than the surrounding rock and therefore develop rows of pits along the face of an outcrop. Their size, 6 to 18 inches or more across, together with their persistence makes an easily recognized physical feature. The few fossils that are found are not very characteristic. The following should be mentioned: Spirifer perlamellosus.

In the discussion and on the maps the Port Ewen and Oriskany are treated together as a single unit as the Oriskany-Port Ewen beds.

(14) *Becraft limestone.* Massive, heavy to thin bedded, light colored, semicrystalline to thoroughly crystalline limestone. More massive beds very pure, 94+% $CaCO_3$. Shaly beds resemble the New Scotland which they pass into at the base. The most characteristic features for field identification are (*a*) pink or light colored spots, (*b*) a more coarsely crystalline condition than any of the associated strata, (*c*) occasional large calcite cleavages to be seen wherever a fossil crinoid base Aspidocrinus scutelliformis is broken, (*d*) the very characteristic fossil Sieberella pseudogaleata, and (*e*) many crinoid stems.

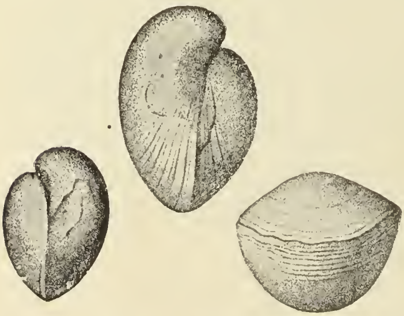


Fig. 4 Sieberella pseudogaleata Hall, the most characteristic index fossil of the Beacroft limestone of the Rondout region

The formation carries many fossils in addition to those given above, among which are Spirifer concinnus, Uncinulus campbellanus.

(15) *New Scotland shaly limestone.* Thin bedded, dark gray to reddish sandy and shaly limestones. The rock breaks out in slabs on weathering and develops red iron stains. It has especially abundant fossils, the most characteristic of which are: Orthothetes woolworthanus, Spirifer macropleura. Other common ones are: Leptaena rhomboidalis, Strophonella headleyana, Ripidomella oblata, Stropheodonta becki.

(16) *Coeymans limestone.* Heavy bedded, dark gray, argillaceous and flinty limestone. The characteristic features for field identification are (*a*) abundant chert nodules, (*b*) the occurrence of coral reef structure and heads of corals, Favosites helder-

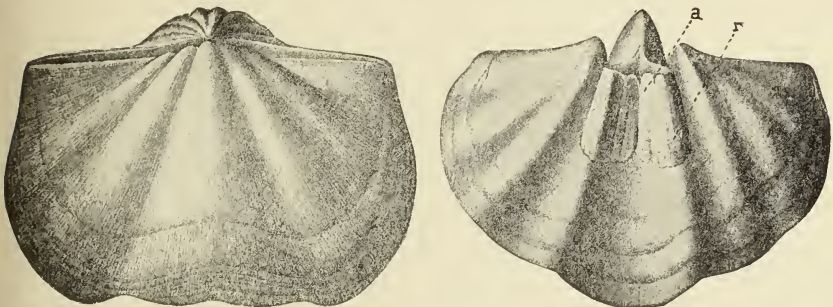


Fig. 5 Spirifer macropleura (Conrad), the most characteristic index fossil of the New Scotland beds in the Rondout region

bergia. The brachiopods Sieberella galeata and Atrypa reticularis are very common.

This formation has a thickness of about 80 feet and is rather distinctly separated from the underlying Manlius. The Coeymans is considered the base of the Devonic system of New York. It is

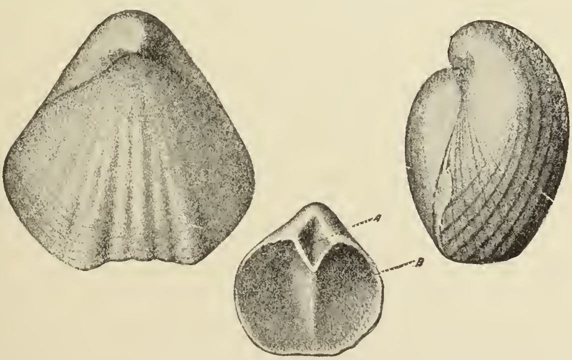


Fig. 6 Sieberella galeata (Dalman), the most reliable index fossil of the Coeymans limestone of the Rondout region

perfectly conformable upon the underlying series and it is evident that in this region there was no important break in the progress of deposition.

e **Siluric strata.** (17) *Manlius limestone.* Lime mud rock, fine textured, dense, with plainly marked sedimentation lines, gray to dark gray color. The most characteristic features in the field are (*a*) fine texture, (*b*) sedimentation lines, as if laid down in quiet waters as a lime mud, (*c*) solution joints sometimes enlarged to

cavelike form into which surface streams disappear (such as Pompey's cave near High Falls), (*d*) mud crack surfaces (in lower beds), (*e*) occurrence of the fossil Leperditia alta.

Its abundant jointing and the tendency to develop solution cavities from them is considered an objectionable character.

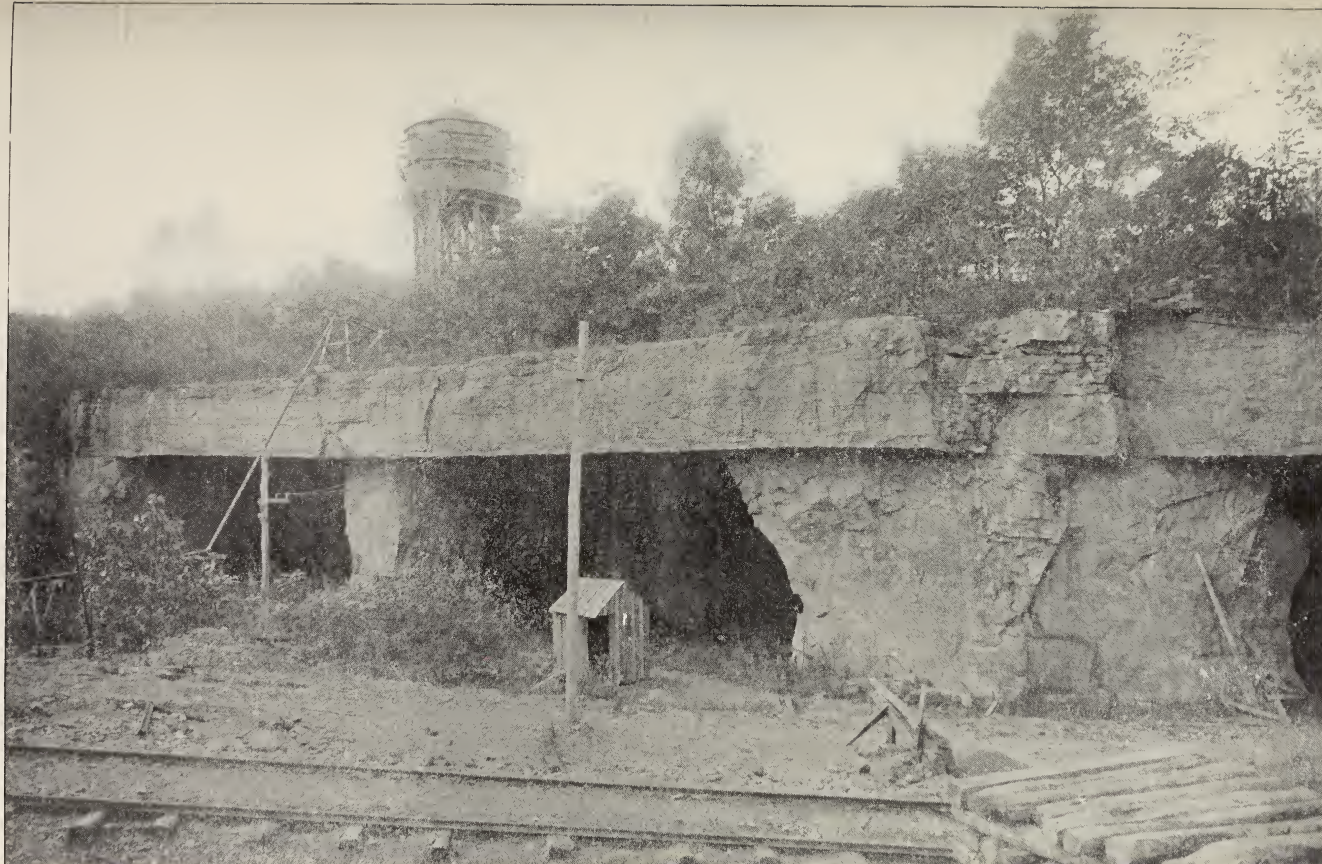
(18) *Cobleskill and cement beds* (limestone). It is not possible without the most painstaking, comparative, chemical and paleontologic research to differentiate the cement layers from the inclosing beds and to assign them all to the subdivisions that are recognized in some previous publications,[1] as the (*a*) *Rondout* cement (*b*) *Cobleskill* limestone, (*c*) *Rosendale* cement, and (*d*) *Wilbur* limestone. There are, however, two workable natudal cement beds, both at Rondout and at Rosendale, with a nonworkable layer between each case, and also one between the lower and the next underlying formation. Whether the two cement beds at Rondout represent the *Rondout* and the *Rosendale* horizons with the Cobleskill between, or whether they should both be regarded as *Rondout* with Cobleskill below, can not concern our present problems. And again, whether or not the two cement beds at Rondout are the same two that appear at Rosendale, or whether they are equivalent only to the upper one with a new lower bed (The *Rosendale*) added in this area and then with the Cobleskill between these two as claimed by Grabau, does not alter the plain fact that the whole series is a physical unit. It is a gray, rather close texture limestone, resembling the Manlius proper, and contains few fossils. It is perhaps even better yet to group all of these limestone beds below the Coeymans into a single unit and call it the Manlius series.

(19) *Binnewater sandstone.* Below the Manlius cement rock series lies the 60–100 foot Binnewater. It is chiefly a well bedded quartz sandstone, almost a quartzite in the upper beds with more shale in its lower portion, in color varying from white to greenish yellow and brown. The rock is rather porous in certain beds and especially along the bedding planes and is not well recemented where crushed by crustal movements. It is confined to the Rondout valley.

(20) *High Falls shale.*[2] Greenish to red argillaceous to sandy shales. The exposures are often a brilliant red while the rock

1 N. Y. State Mus. Bul. 92 (Grabau), p. 311–13; N. Y. State Mus. Bul. 80 (Hartnagel), p. 355–58; N. Y. State Mus. Bul. 69 (Van Ingen and Clark), p. 1184, 1185.

2 The term given by Hartnagle. N. Y. State Mus. Bul. 80. p. 345.



Limestone beds of the Rosendale cement region. The Beach mine near Rosendale. (Photograph by T. C. Brown for the Board of Water Supply)

Interior of the Norton cement mine, Binnewater, N. Y., showing the thickness and dip of one of the cement beds and the method of mining. (Photograph by T. C. Brown for the Board of Water Supply)

from drill cores is seldom highly colored. The protected beds are more commonly greenish in color and contain much iron sulphide. Occasional thin limestone beds occur in the upper portion at High falls — one of 4 feet forms the lip of the lower fall. The High Falls shale is confined to the Rondout valley and on the line of the aqueduct is 67–100 feet thick.

(21) *Shawangunk conglomerate.* The Shawangunk is a conglomerate and sandstone. The constituent pebbles are almost wholly quartz, well worn, and varying in size from that of sand to pebbles of several inches diameter. But for the most part the pebbles are small, abundantly mixed with sand, bound together by a silicious cement. Rarely a true quartzite is developed and still more rarely a shaly facies. The rock is therefore very hard, brittle, and in the undisturbed portions fairly impervious and resistant. But it suffers from crushing along zones of disturbance in folding and faulting and these zones are very imperfectly recemented. It is a durable rock, very resistant to ordinary decay, but forms great talus slopes. It is used for buhrstones (millstones), etc. It varies in thickness on the lines of the aqueduct from 280–400 feet. The rock is limited in its northward extension to this district — southwestward it is much more broadly exposed in the continuation of the Shawangunk range.

The Shawangunk completes the conformable Siluro-Devonic series down to the erosion interval at the close of the Ordovicic. The series of conglomerates, sandstones, limestones, and shales make an imposing column approximating 3000 feet of strata differentiated with more or less ease into 15 separate and mapable formations and a possible 5 or 6 more with careful paleontologic work. The series begins with the capping beds of the Shawangunk range and its northward extension toward the Hudson river at Rondout and Kingston, and thence westward constitutes the rock floor while its structures control the surface configurations far beyond the limits of the region under consideration. Immediately to the north and partly within the area here treated is the famous Rosendale cement region, the pioneer cement district of America and for many years the best producer. The strata used are almost exclusively the upper members of the Siluric ("cement beds") closely associated with the Cobleskill between the Manlius proper and the Binnewater sandstone. Rarely the Becraft from the Devonic series furnishes some cement rock.

f **Cambro-Ordovicic formations.** Between the Precambric metamorphics of the Highlands beneath and the Siluro-Devonic

sediments of the Shawangunk range and the Catskills above, lies a series of quartzites, limestones and slates less complexly disturbed than the older and more disturbed than the younger series — set off from both by unconformities representing time intervals that cover both folding and erosion. They are of more than 4000 feet thickness — how much more it is impossible to estimate because of the obscurity of data in the slates. There are very few fossil forms preserved in them. The series is, however, readily and sharply separable into three formations that may be mapped upon lithologic characters alone. They are of most importance in the Wallkill valley, Moodna creek, Newburgh, Fishkill, New Hamburg and Poughkeepsie districts. Their character, structure, and conditions have required careful consideration in the decisions on the Wallkill and Moodna siphons and in the discussions on the proposed Hudson river crossings [*see* Hudson river crossings, pt 2].

(22) *Hudson River slates.* The upper member of the Cambro-Ordovicic series is in itself complex. Prevailingly it is a slaty shale, occasionally it is a sandstone or shaly sandstone, or a simple shale; still more rarely it is almost a true slate, and very rarely a phyllite. The constituents vary from prevailing clay to quartz sand repeatedly in almost every locality. It is probable that as a rule the upper portions are the more heavily bedded and arenaceous. The rock is excessively affected by the dynamic movements that have at least twice disturbed it. A slaty cleavage in the more argillaceous members is most noticeable, but almost everywhere the strata are strongly tilted, crumpled, broken, faulted, or crushed in a most confusing way. This together with an original obscurity in bedding, and the obliteration by subsequent shearing of much that did exist, makes it impossible to reconstruct the complicated structure or compute the thickness of the formation. It is of such physical character as to absorb within its own limits much of the disturbing movements, and neither the formations above nor immediately below are so extensively and intimately affected. The formation is widely exposed and forms the bed rock over very large areas. Almost everywhere it is impervious to water, easy to penetrate by drill or tunnel, and resistant to decay. A few Ordovicic fossils may be found, the most characteristic being Dalmanella testudinaria.

(23) *Wappinger limestone.*[1] (In part Cambric, and in part

[1] The Wappinger Valley limestone of Dwight (1879) and Dana. The Wappinger limestone of Darton and others.

Bonticou crag. One of the peaks of the Shawangunk range. The rock is Shawangunk conglomerate. Bonticou tunnel passes beneath this point. (Photograph by Board of Water Supply)

A trench through Hudson River slates and sandstones for cut-and-cover aqueduct construction on the Newburgh division. (Photograph by Board of Water Supply)

Ordovicic). The formation is prevailingly of a compact, fine texture, dark gray, either massive or strongly bedded limestone. Where the stratification is very plain there are light and dark layers and an abundant silicious intermixture. In many outcrops the rock is so massive that even the dip and strike are obscure. Some places the rock is fine crystalline, almost a micromarble. On weathered surfaces it almost always exhibits a crisscross etching which marks the traces of rehealed cracks. From these it is seen that many of the apparently massive compact beds have at one time been extensively crushed. In many places there is scarcely a square inch wholly free from these evidences. The formation is best exposed in the wide belt that extends southwestward from the vicinity of Poughkeepsie and crosses the Hudson at New Hamburg into the Newburgh district. It undoubtedly underlies the slates in the rest of the adjacent area. There are few fossils and they are rarely found.

(24) *Poughquag quartzite.* Below the Wappinger limestone and upon the upturned and eroded edges of the Highlands gneisses lies a quartzite of variable thickness but which reaches at least 600 feet. It is a strongly silicified quartz sandstone — a quartzite by induration. It is strongly bedded but seldom shaly. Traces of schistosity may appear in certain zones and this is somewhat strongly developed outside of the area at the type locality (Poughquag, N. Y.).

Only fragments of trilobite spines have been found in this formation within the district.

g **Later crystallines south of the Highlands.** South of the Highlands proper except at one locality (Peekskill creek valley and its southwestward continuation through Tompkins Cove and Stony Point) the rocks are all much more thoroughly crystalline. There are two formations, and in places traces of a third, above the Grenville gneisses (Fordham gneisses and associates). These are known locally as *Manhattan* schist, *Inwood* limestone, and *Lowerre* quartzite. In Westchester and New York counties the quartzite is rarely found, and in a considerable proportion of those places where it does occur its relations are more consistent with the gneisses below than with the limestone-schist series above. This is true indeed of the type locality (Lowerre). There are, however, at least two points where the occurrence favors the reverse interpretation, so far as any is shown, and therefore a quartzite may be regarded as finishing the series, and making uncertain but probably unconformable contact with the underlying gneisses.

This series together with the gneisses below constitutes the bed rock and controls the underground conditions for all of the line south of the Moodna valley, 50 miles above New York. All of the southern aqueduct, and the New York city distribution conduits are wholly concerned with these rocks, and two divisions of the northern aqueduct have a large proportion of their work in them.

It is not wholly clear what age these crystallines represent. It is certain that the underlying gneisses are Grenville and that the metamorphic quartzite, Inwood, Manhattan series, is Post-grenville. It is possible that these latter are also Precambric. But usage following the correlations of Dana[1] and in the absence of as good evidence from any other source has regarded them as the Cambro-Ordovicic crystalline equivalents of the Poughquag-Wappinger-Hudson River series of the north side of the Highlands. The writer has elsewhere shown[2] that the evidence and arguments are not all on one side and that considerable doubt may still be entertained on that point. There is no object in following that argument here or in modifying the treatment here followed of making them a distinct series. Even if they should prove to be the exact equivalents of the Hudson River-Wappinger-Poughquag series the formations are physically so different and require so different treatment in discussion that they must for our present purpose be regarded as an essentially distinct series. From that standpoint alone the usage here followed is justified. The Manhattan schist of Westchester county as a type differs as much petrographically from the Hudson River formation of the Newburgh district as the Catskill formation of Slide mountain differs from the Jameco gravels of Long Island. In a discussion where physical or petrographic character is in control there is no doubt about the advisability of treating the two separately.

(1) *Manhattan schist.*[3] This is primarily a recrystallized sediment of silicious type. It occurs as a nearly black or streaked, micaceous, coarsely crystalline, strongly foliated rock. The chief constituents are biotite, muscovite and quartz. Quartz, feldspar,

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1 Dana, J. D. On the Geological Relations of the Limestone belts of Westchester county, N. Y. Am. Jour. Sci. 20:21–32, 194–220, 359–75, 450–56 (1880); 21:425-43; 22:103-19, 313-15, 327-35 (1881).

2 Berkey, Charles P. "Structural and Stratigraphic Features of the Basal Gneisses of the Highlands." N. Y. State Mus. Bul. 107 (1907), p. 361–78.

3 Manhattan schist of Merrill. N. Y. State Mus. 50th An. Rep't, 1:287. Same as "Hudson schist," of N. Y. city folio no. 83.

garnet, fibrolite and epidote also occur in large quantity. Occasional streaks or masses are hornblendic instead of micaceous. These are interpreted as igneous injections. They are especially abundant on Croton lake and near White Plains.

It is essentially a quartz-mica schist. But it is almost everywhere very coarse textured and hardly ever exhibits the fine grained, uniform structure of typical schist. Its abnormal make-up — the predominance of biotite and quartz — is the best defense for its petrographic classification. The abundance of mica makes it a tough rock but not very hard. The joints and fractures formed in later movements are not healed and zones of bad shattering are susceptible to considerable decay. These crushings are sufficiently common to encourage borings to tap their content of water for small family use throughout Westchester county; but they do not represent large circulation in any case. On the whole, the rock if fresh is good and durable. It may, though rarely, carry considerable sulphide. Practically all of the strictly original sedimentation marks are destroyed by metamorphism. The formation has great thickness, but because of the destruction of original bedding lines by recrystallization and additional complication by most complex folding, shearing, crushing and faulting, the structure can not fully be unraveled and the thickness can not be estimated with any approach to accuracy of detail. But there is probably a thickness represented of several thousand feet.

(2) *Inwood limestone or dolomite.* This formation lies beneath the Manhattan. It is everywhere coarsely crystalline either massive or strongly bedded, often very impure with development of secondary (recrystallized) mica (phlogopite) and other silicates, especially tremolite. It is essentially a magnesian limestone or dolomite in composition. There is an occasional quartzose bed in the midst of the limestone as at East View. The upper beds are most charged with mica and occasionally beds attacked by alteration have much green, flaky chlorite. There are occasional interbeddings of limestone and schist as a transition facies.

The coarser grades upon exposure to weathering readily yield by disintegration to a lime (calcite) sand resembling roughly an ordinary sand in general appearance. At Inwood, the type locality, this disintegration is so pronounced that great quantities are readily shoveled up and used for various structural purposes in the place of other sand. This dolomite is especially liable, as now shown by extensive explorations, to serious decay to great depth. The underground circulation seems to attack the micaceous beds with great

success and in some places the residue after this solvent action is of the consistency of mud. A nearly vertical attitude of the beds accentuates the opportunity. The most troublesome piece of ground encountered on the whole line of the New Croton aqueduct, constructed in 1885, was in a weak zone and crevice in the Inwood near the village of Woodland on the margin of the Sawmill valley [*see* discussions of Bryn Mawr siphon and New York city distributions in part 2].

The thickness probably varies but in many places where there is only a narrow limestone belt it is due more to shearing or faulting out than to original thinning. The most satisfactory estimates are based on the explorations at Kensico dam and the field observations at 152d street. They indicate an approximate thickness of 700 feet. But in all cases either the margins are obscured or there is possibility of faulting to modify measurements. There are no fossils. Weathering and erosion has almost everywhere developed valleys or depressions especially small tributary valleys in all formations, but as pointed out years ago by Professor Dana the principal valleys prevailingly coincide with the limestone belts.

(3) *Lowerre quartzite.* At Hastings-on-Hudson and again near Croton lake, there is a quartzite that appears to be conformable with the Inwood above. There is possibly more than 50 feet. It is a simple, clean quartzite. The other quartzites of Westchester and New York county have a more distinct relationship to the underlying gneisses with which they are conformable. The Lowerre of the type locality is of this second class. In the great majority of places where this bed would be expected to occur there is not a trace of it.

h **Older metamorphic crystallines (Grenville series).**[1] "The lowest and oldest, as well as the most complex in structure and rock variety, of all the formations of the Highlands region of southeastern New York is essentially a series of gneisses." Cutting these gneisses as intrusions of various forms are a great number and variety of more or less distinctly igneous types. In form they vary from small dikes or stringers to great batholithic masses; in composition, from the extremely basic peridotites or pyroxinites of

[1] This interpretation of the larger relations of the complex gneisses constituting the basis of the series, lying below the Manhattan-Inwood-Lowerre series, was presented by the writer under the title: Structural and Stratigraphic Features of the Basal Gneisses of the Highlands. N. Y. State Mus. Bul. 107 (1907). p. 361–78. The accompanying description is largely an abstract of this paper.

the Cortlandt series to the very acid granites of Storm King mountain or the granophyric pegmatites of North White Plains; and in relative age they likewise vary from a period antedating the chief early metamorphic transformation of the Grenville to Postmanhattan time. But these clearly igneous types attain a considerable prominence as separable units in the practical consideration of the problems of the project and on that account the chief ones will be more fully described under the next group.

The older portion — the various schists, banded gneisses, quartzites, quartzose gneisses, graphitic schists, and serpentinous and tremolitic limestone, forming the complex through which and into which the igneous masses have been injected — form together an interbedded series that was originally a sedimentary group. There is nothing known that is older in this region. Its characteristics and relations mark it as in all probability the equivalent of the "Grenville" of the Adirondacks and Canada.

No single type and no single characteristic can be given as a simple guide to the identification of this formation. The prevalence of certain varieties or groups of these and the strongly banded structure give a certain degree of character that forms a reasonable working base. The formation includes banded granitic, hornblendic, micaceous and quartzose gneisses; mica, hornblende, chlorite, quartz and epidote schists; garnetiferous, pyritiferous, graphitic, pyroxenic, tremolitic, and magnetitic schists and gneisses; crystalline, tremolitic, and serpentinous limestones, aphi-dolomites, serpentines and quartzites; pyrite, pyrohitite and magnetite deposits. This is the basal series. But it is complicated by a multitude of bands of granitic and dioritic gneisses that represent injections of igneous material at a time sufficiently remote to be subjected to most of the early metamorphic modifications. The equally abundant occurrences of quartz stringers and pegmatite lenses though of later origin can not be separated from this complex mass and the whole must be regarded as a physical unit. The occurrence of interbedded limestones and quartzites together with a variety of conformable schists and banded rocks, marks the formation as essentially an old recrystallized sediment.

No member of this older unit of the basal complex is sufficiently prominent to indicate a great break or change up to the time of the first great dynamic movements and igneous outbreaks. The following comparatively constant members are sometimes persistent enough to be considered formational units, but even more commonly

are obscure as to boundaries or are of too small development to map separately.

(4) *Interbedded quartzite.* Always a quartzite schist and always exhibiting conformity with the banded gneisses and schists. This is regarded as the uppermost member.

(5) *Fordham gneiss* (Banded gneiss). Granitic and quartzose black and white banded gneisses and schists of very complex composition and structure.

(6) *Interbedded limestones.* Crystalline. Interbedded, very impure, serpentinous and tremolitic, granular dolomites, usually 2 to 50 feet thick, possibly reaching a thickness of more than 100 feet in a few cases.

(7) *Older intrusive gneisses.* Variable types, mostly granites or diorites, strongly foliated sills.

Many are of very obscure relations. The line of close distinction between recrystallized sediment, segregations accompanying that change, and true igneous injection can not be drawn.

i **Special additional igneous types.** Under this heading are included the massive or little modified, not at all or only moderately foliated, igneous masses of later origin and local rather than regional development. In some cases, however, they are of decidedly controlling importance in the local geology and rise to the status of definite formations. The most noteworthy of these within reach of the aqueduct explorations are:

(8) The Storm King Mountain gneissoid granite
(9) The Cat Hill gneissoid granite (central Highlands)
(10) The Cortlandt series of gabbro-diorites (near Peekskill)
(11) The Peekskill granite (east of Peekskill)
(12) The Ravenswood granodiorite (Long Island City)
(13) The pegmatite dikes and lenses (segregational aqueo-igneous type)

(8) *The Storm King gneissoid granite* is one of the largest of the clearly igneous and less completely foliated types. It constitutes the whole of Storm King mountain and the larger part of Crows Nest on the west side of the Hudson, and, crossing the river, forms the chief rock of Bull hill and Breakneck ridge. It is a rather acid, coarse grained, reddish granite with considerable gneissoid structure in a large way [*see* Hudson river crossings, pt 2].

(9) *The Cat Hill gneissoid granite* is not essentially different from the Storm King type as a physical unit. Its occurrence at a

South portal to Garrison tunnel on the Peekskill division. The rock is a badly jointed granite belonging to one of the intrusives of the older gneisses. (Photograph by Board of Water Supply)

different point (Cat hill), widely separated by other types from the Storm King locality, and in rather large development, is worthy of separate note. It is cut, of course, in the long tunnel through Cat hill.

(10) *The Cortlandt series of gabbro-diorites* occupies an area of about 20 square miles between Peekskill and the Croton river, nearly all on the east side of the Hudson. It includes a very complete range of coarse grained, massive, igneous rocks from soda granites, grano-diorites and quartz-diorites to true diorites, norites, gabbros, pyroxenites, and peridotites. They doubtless represent stages or portions in the differentiation of a magma. The interrelations are only partially determinable, and the petrographic distinctions in detail are not useful here. The area occupied by the Cortlandt series has an uneven hilly surface with no structural trend, and makes the most striking contrast to the ridge and longitudinal valley structure of the rest of the region of the crystallines.

(11) *The Peekskill granite,* a white, or pink massive, very coarse grained, soda granite, occupying approximately 4 square miles immediately north of the Cortlandt area 2 miles east of Peekskill, is believed to be genetically related to the Cortlandt series. The evidence in favor of such a relationship has been gathered in the prosecution of this work and has not been published. But it may be said that the textures, structure, age, relationship to older crystallines, interrelations with the Cortlandt series, consanguinity of mineralogy, and composition all point toward the above relationship. In essential relations, therefore, it is the acid extreme of the Cortlandt series. Its economic features, however, are of sufficient importance and its easy differentiation from the regular Cortlandt types require that it should have separate treatment.

(12) *The Rravenswood grano-diorite* occurs chiefly in Brooklyn. It is a slightly foliated mass intrusive in the Fordham gneiss and is doubtless connected in origin with the sources of many of the hornblendic intrusive bands in the Fordham and Manhattan formations in the district. It covers a known area of about 5 or 6 square miles and may be more extensive. The rock is suitable for structural material and has required consideration in the study of "Distributary conduits" [*see* pt 2 East River section].

(13) *Pegmatites.* The pegmatites and pegmatitic granophyric masses of all kinds are of almost universal distribution in the foliated crystallines. They vary from quartz bunches or stringers to pegmatitic lenses and irregular masses, and to definite granitic

or pegmatic dikes. In many places they constitute a large proportion of the formation in which they occur. They doubtless vary in age, but for the most part seem to belong to the later period of metamorphism. Many of them are massive and largely free from foliation. They no doubt have a complex origin between simple aqueous segregation on the one side and true igneous intrusion on the other.

Summary of formations

Group a Quaternary deposits

(1) Glacial drift Till and modified drift, extra marginal outwash, sands and gravels, etc.	Occurs as a surface mantle over nearly all of the region under discussion, except the immediate sea margin

UNCONFORMITY

Group b Tertiary and Cretaceous deposits

(2) Tertiary outliers (*a*) Pliocene littoral deposits (Bridgetons?) (*b*) Miocene "fluffy" sand (Beacon hill) (3) Upper Cretaceous beds (*a*) Lignitiferous sand (marl series) (*b*) Matawan beds (clay marls) (*c*) Raritan (clays and sands)	Confined to Long Island, Staten Island and the New Jersey coast

UNCONFORMITY

Group c Jura-Trias formations

(4) Palisade diabase intrusion (5) Newark series of conglomerates, sandstones and shales	Confined to the west side of the Hudson south of the Highlands

UNCONFORMITY

Group d Devonic strata

(6) Catskill, white and red conglomerate (1725 feet)
(7) Oneonta (upper flagstone) (3000 feet)
(8) Ithaca and Sherburne (lower flagstone) (500 feet)
(9) Hamilton and Marcellus shales (flagstone and shales) (700 feet)
(10) Onondaga limestone (200 feet)
(11) Esopus and Schoharie shales (silicious) (800 feet)
(12) Oriskany and Port Ewen transition (100 feet)
(13) Port Ewen limestone and shale (150 feet)
(14) Becraft limestone (75 feet)
(15) New Scotland shaly limestone (100 feet)
(16) Coeymans cherty limestone (75 feet)

Confined to the Catskills, the Esopus and Rondout valleys, the northern extension of the Shawangunk range, and Skunnemunk mountain near Cornwall

Group e Siluric strata

(17) Manlius limestone (70 feet)
(18) Cobleskill limestone and cement beds (30 feet)
(19) Binnewater sandstone (50 feet)
(20) High Falls shale, including small limestone beds (75–80 feet)
(21) Shawangunk conglomerate (250–350 feet)

Confined to the Rondout and Esopus valleys and the northerly extension of the Shawangunk range, through the cement region of Rosendale, Binnewater, Rondout and Kingston, and a small outlier at Skunnemunk mountain

UNCONFORMITY

Group f Cambro-Ordovicic formations

(22) Hudson River slates, shales, and sandstones (very thick) (Ordovicic) more than 2000 feet (23) Wappinger limestone (1000 feet) (in part Cambric and in part Ordovicic) (24) Poughquag quartzite (600 feet) (Cambric)	Especially prominent a surface formations i the Shawangunl range, the Wallkil valley, and the regioi eastward and southward to the Highlands, on both side of the Hudson

Group g Later crystallines (South of the Highlands)

(Uncertain age)

(1) The Manhattan schist, a thoroughly and coarsely crystalline sediment of uncertain age — generally supposed to be equivalent to the Hudson River slates, (Ordovicic) but here separated without necessarily raising that question because of their very different physical and petrographic character (2) Inwood limestone (or dolomite), a magnesian crystalline limestone of uncertain age, generally supposed to be the equivalent of the Wappinger (Cambro-Ordovicic), but here enumerated separately without necessarily raising that question because of their very different lithologic character and associates (3) Lowerre quartzite, an occasional quartzite of uncertain relations and very limited development	Confined to the region east of the Hudson river and south of the Highlands proper, occupying the region from the Highlands to Long Island

UNCONFORMITY

Group h Older crystallines (Highlands gneisses)

(Grenville series of metamorphics and intrusives — Precambric)

(4) Interbedded quartzite. A quartzose schist (5) Fordham gneiss (chiefly sedimentary). Granitic and quartzose banded gneisses and schists of very complex development (6) Interbedded limestones (Grenville) associated with the Fordham gneisses	Grenville Series	Formations characteristic of the Highlands and some of larger ridges extending southward to New York city. A series, which in petrographic variety, is as complex as all of the rest of the formations of the region together
(7) Old intrusions. Large and variable masses of granitic gneisses of igneous origin cutting the Grenville series, such as Storm King granite, Cat Hill granite, etc.		Postgrenville in age

Group i Special additional igneous types

(8) Storm King gneissoid granite, Storm King-Breakneck district (9) Cat Hill gneissoid granite. Garrison district (10) Cortlandt series of gabbro-diorites. Peekskill-Croton district (11) Peekskill granite. A boss, related to the Cortlandt series. Peekskill district (12) Ravenswood grano-diorite. A boss. Brooklyn, Long Island City and Southern Manhattan (13) Pegmatites. Dikes, lenses, segregations of general distribution	These are masses of strictly igneous origin (except the pegmatite) and of larger development which either because of their abundance (*pegmatites*) or large area (*Cortlandt*) or economic features (*Peekskill*) or important bearing upon the plans of the aqueduct (*Storm King*) are worthy of separate note.

3 Major structural features

In addition to the simpler structural characters of the strata, already sufficiently emphasized in the individual descriptions, there are numerous others of more general relation whose value and influence it is necessary to consider in many of the practical problems. Those of most importance are the unconformities, folds and faults. They are directly related to continental elevation and subsidence, to mountain forming movements and denudation processes, to metamorphism and to igneous intrusion.

a **Sedimentation structures.** In the younger strata the principal structures are those of bedding, stratification, conformable succession, etc., characteristic of all sediments of such variety of type. These are prominent in the older groups of formations down to the crystallines, but the earlier Paleozoics are also affected so profoundly by folding and faulting that attention is more concerned with these induced or secondary structures.

b **Unconformities.** Time breaks, with more or less disturbance of strata and accompanied by erosion, are numerous.

(1) That between the glacial drift and the rock floor is the most profound. It causes the glacial drift to lie in contact with every formation of the region from the oldest gneisses of the Grenville series of the Highlands to the traces of Miocene beds of Long Island.

(2) The interval between the Pliocene and the Upper Cretaceous beds is more obscure and hardly reaches the importance of an unconformity. It is probably more nearly of the value of a disconformity or of an overlap, and the very limited development of the overlying beds in the region gives little chance for determining relations in much detail.

(3) The overlap and unconformity between the Cretaceous and Triassic. A condition determinable only on the New Jersey side of the Hudson river.

(4) The unconformity between the Triassic and underlying formations of different ages. An interval representing mountain development and extensive erosion, in which the chief movement probably belongs to the close of Paleozoic time and includes the Appalachian folding.

(5) Unconformity between Siluric and the Ordovicic strata. An interval representing mountain development, folding and erosion, in which the movement known as the Green Mountain folding took place.

(6) Unconformity between the Poughquag (Cambric) quartzite and the underlying crystallines. An interval in all observable cases of great length and profound changes involving mountain folding, metamorphism of the profoundest sort, and extensive erosion.

(7) Among the crystallines of the south side of the Highlands there is one break of similar importance, between the Inwood limestone and the underlying gneisses. Whether or not it is the same as no. 7 above is not clear, but even if it represents the same break the relations are somewhat different in degree and character because of the lack of quartzite in almost all cases.

Within the gneisses of the Grenville series and their associates of all kinds there are no breaks of the unconformity type known. The contacts are eruptive in character, or are displacements instead.

c **Folds and mountain-forming movements.** All of the formations from the oldest up to and including the Lower Devonic strata are folded. Many of the smaller (minor) folds exhibit complete form in the stream gorges of the district, but all of the larger ones, the main folds, have in earlier time been eroded to such extent that the series is beveled off and only the truncated edges are to be seen, exhibiting strata standing more or less perfectly on edge, and making restoration of the form a very difficult or impossible task. This is only partially accomplished in the Siluro-Devonic margin along the Shawangunk range; it is more complete in the Cambro-Ordovicic north of the Highlands, and it reaches its most perfect development in the crystallines of the Highlands and New York and Westchester counties. These differences correspond roughly to the differences in age of the strata, and, taken together with the evidence of the profound unconformities, indicate that mountain-forming movements of far-reaching importance visited the region no less than three times. Each time of such disturbance, of course, the underlying older series was affected by the movements of that epoch in addition to any previous ones, and as a consequence the older is to be expected to show more complexity of such structures. Each succeeding series separated by such activity is therefore one degree simpler in structure.

Of these three epochs of great disturbance, one is (1) Precambric and corresponds to the time interval marked by the unconformity between the Poughquag quartzite and the gneisses; a second (2) is Postordovicic and corresponds to the time interval marked by the unconformity between the Hudson River slates and the Shawan-

gunk conglomerates, and the last (3) is Postdevonic (probably Postcarbonic, judging from neighboring regions of similar history) and has left as its most important evidence in this district, the excessively complicated sharp foldings and thrusts of the Shawangunk range and its extension in the Rosendale cement district.

Kinds. As to forms produced there are no usually described types that are not to be found here. The simpler forms of anticlines and synclines, both open and closed, symmetrical and unsymmetrical and overturned, are all common. The isoclinal is common in the gneisses. In each epoch of folding the compression forces were effective chiefly in a northwest-southeast direction producing arches and troughs whose axes trend northeast-southwest. This is the trend of the main structures throughout the region.

The extent of crustal shortening accomplished by this series of compressions is undetermined, but that it amounts to a total of many miles is indicated by the fact that over broad areas the strata stand almost on edge. Furthermore, in the older Highlands and in portions of the Hudson river districts the folds have been slightly overturned so that commonly the strata on both limbs dip in the same direction (toward the southeast). This seems to indicate a strong thrust from the southeast. All stages between the gentlest warping to strongly overturned folds, and from minute crumbling to folds of great extent and persistence are to be seen.

The effect of all the folding is chiefly to present a series of upturned strata to erosion and encourage a subsequent development of valleys along the softer beds bordered by ridges of the more resistant types.

As the axes of the folds lie in a northeast-southwest direction, this gives a marked physiographic development of ridges and valleys of the same trend, a most conspicuous topographic feature of southeastern New York.

d **Faults.** Accompanying the folding in each epoch, and especially the stronger overthrust movements there has been a tendency to rupture and displacement. These breaks are known as faults. Multitudes of them are of minute proportions and practically neglectable in a broad view, but many also are of large extent, traceable across country for many miles and indicating displacements in some cases of many hundreds of feet. For the most part these faults are of the thrust type and wholly consistent with the folds in origin. They run generally in a northeast-southwest direction, especially the larger ones, and frequently form the separation planes between different formations. Occasional cross

A fold in the New Scotland limestone on Rondout creek. (Photograph by Columbia University Summer School in Geology, 1908)

A thrust fault in the limestone beds on Rondout creek near Rosendale. (Photograph by Columbia University Summer School in Geology, 1908)

faults occur (with northwest-southeast direction across the strike), but so far as is known they are always of minor consequence. In rare instances, the trace of a fault line on the surface describes curious curves, such as that at Cronomer hill above Newburgh, apparently inconsistent with the chief structural trend, but a study of the whole geologic relation in such cases shows them to be connected with the projecting spurs of underlying formations which in any large thrust movement plow their way with some success through the younger overlying, less resistant, strata. They differ in no material way from the other more simple looking lines.

Both normal and thrust faults occur, but the thrust type appears to be most common.

The amount of displacement or throw is extremely variable. The larger faults represent movements of several hundred feet. In rare cases the movement may be as much as 2000 feet.

The effects may be grouped as follows: (1) the appearance of formations out of their normal order, i. e. contacts between formations that do not normally lie next to each other; (2) the production of escarpments, i. e. steep cliff-bordered ridges; (3) the development of zones of more or less extensively crushed rock along the principal plane of movement; (4) the determination of location for stream courses and gulches and valleys that cross the formations.

All of these effects are more noticeable and better preserved for the later movements than for the earlier ones. Many of those dating back to the earliest epoch, affecting only the crystalline rocks of the Highlands, are not readily detected. Most of the breaks have been healed by recrystallization and the contacts are often as close and sound as any other part of the formation.

But this is not so true of the later epochs — and in them a good deal depends upon the type of rock affected. The more brittle and hard and insoluble types are more likely to still have open seams and unhealed fractures than the softer and more easily molded formations. In some of these, recent water circulation has still further injured the fault zones by introducing rock decay to considerable depth. Because of the more ready circulation in them, it is noticeable that some of the extensive decay effects are produced in crystalline rocks that otherwise very successfully resist destruction. On the whole the softer clay shales and slates are less likely to preserve open water channels of this sort than any other formation of the region.

No part of the region is wholly free from faulting effects, excep perhaps a part of Long Island. The Catskills also are very littl affected — so little that this type of structure has not require consideration in the vicinity of Ashokan reservoir. But all parts o both the northern and southern aqueduct system have had thi feature to consider.

Further discussion of the specific local problems introduced b faulting and folding is given under the problems of part 2. A considerably more extended comment on the age of fault movemen is given under the heading " Postglacial faulting."

4 Outline of geologic history

Most of the general features of geologic history have been involved more or less in the foregoing discussion. It is impossible to wholly separate matters that are so intimately interrelated even though it is convenient to think of or consider one phase at a time. But it may serve a useful purpose to summariz the steps of progress as illustrated by local geology from the earliest geologic time to the present.

a **Earliest time.** (Prepaleozoic, Agnotozoic, Proterozoic, or Azoic Era). There is little doubt that the oldest rocks known in this region are representatives of a time of regular sedimentation Conditions favored the deposition of silicious detritus of variable composition with an occasional deposition of lime, nearly always in very thin beds. What these sediments were laid down upon or where they came from are unsolved questions. The remnants of them that are still preserved are the basis of the " Grenville series " as interpreted in this area, and are the basal (oldest) members of the " Fordham " or " Highlands gneisses."

How long ago this series was deposited is not known. It can be stated only approximately even in the rather flexible terms used in historical geology. It is older than any Paleozoic strata (Precambric), probably very much older. It is even possible that this series is as much older than the Cambric as that period is compared to the present. In short, it is not known, and there is apparently little immediate likelihood of finding out even to which of the several subdivisions of the Prepaleozoic this series belongs. It is certain that before the Cambric sandstones of the Paleozoic era had begun to form, this older series was disturbed by crustal movements, folded, metamorphosed, intruded by igneous injections, elevated above the water (sea) level of that time and eroded by surface agencies. These movements and steps there is no doubt of.

When subsidence[1] again depressed the area beneath the sea the deposition of sands that we now call Cambric (Poughquag) quartzite began.

b **Early Paleozoic time.** With the sedimentation upon this old crystalline rock floor a long time of apparently continuous deposition began which ultimately resulted in the accumulation of several thousand feet of sandstones, limestones, and sandy or clayey shales that are now known as the Cambro-Ordovicic series (Poughquag-Wappinger-Hudson River series). But at the close of Ordovicic time or late in that period another crustal revolution began. The whole region was again compressed into mountain folds, faulted, sheared, metamorphosed, elevated above sea level, and subjected to erosion. This corresponds to the Green mountains folding of Vermont.

With the next subsidence and a return of sedimentation a new series began to form. The break marking the occurrence of all these changes, known locally as the Postordovicic unconformity, represents a considerable portion of Siluric time.

c **Middle Paleozoic time.** The earliest deposits of this series, which continued to accumulate through late Siluric and all of Devonic time, were heavy conglomerates very unevenly distributed over the new rock floor. These are the so called Shawangunk conglomerates, a formation that within the boundaries of this immediate area and within a distance of 20 miles varies from a thickness of more than 300 feet to almost nothing. But for the most part, sedimentation was regular and fairly continuous and of immense volume. The whole series of conglomerates, sandstones, shales, grits and limestones belonging to the later Siluric and the Devonic are included. Not all are believed to be marine however. The Catskill and Shawangunk conglomerates may well be of continental type.

Long after the deposition of all of these strata another crustal disturbance, for at least the third time, repeated the process of mountain-folding and erosion. This was the time of the Appalachian mountain-folding. In this region it caused a wonderfully complex development of folds and faults that are especially important and determinable as to type and age in the Rondout cement region. The movement, of course, affected all of the older formations as

[1] There may possibly be an intermediate stage, practically a duplication of the whole as given above, between the very oldest and the Cambric, represented in the "later crystallines," but this may as well be neglected for the present.

well, but on them, already disturbed by earlier displacements, the features chargeable to the disturbance can not always be distinguished from older ones. All three of the mountain-forming compressions seem to have been controlled by the same relationship of forces and adjustments of movement, for the results are in each case the production of folds or faults of similar orientation and a final structure of uniform trend.

Deposition had been going on for ages, chiefly on the west and north side of the older crystallines; but with a return of sedimentation a decided reversal is noted. The Atlantic border is depressed and much of the interior region seems not to have been subjected to further deposition from that time even to the present.

d **Mesozoic time.** Again conglomerates, sandstones and shales were laid down upon an eroded floor. From their condition and lithology it is believed that they are partly of continental, flood plain, origin. The series is thick, generally assigned to the Triassic period and is extensively developed. During the time of accumulation and to some extent subsequent to it, there was extensive igneous activity pouring out and intruding basic basaltic matter in large amount. The Palisade diabase sill, and the Watchung Mountain basalt flows are the best examples.

At a later time small faulting occurred making frequent displacements in this series. But mountain-folding has not again visited the region. Such breaks as there are, are of the nature of overlaps and disconformities rather than of the revolutionary history indicated by a true unconformity. One of these intervals occurs in the Mesozoic between the Triassic and Cretaceous. Above it the thick series of Cretaceous shales, marls, sands and clays are developed. Succeeding this series a similar interval represents the earliest Cenozoic time.

e **Early Cenozoic time.** The earliest Cenozoic (Eocene and Oligocene) has no sedimentary record within this region.

There are small remnants of deposition representing Miocene and Pliocene time. Above these again the record is blank up to the time of the glacial invasion.

f **Late Cenozoic time — glacial period.** By some combination of conditions not very well understood, the chief features of which no doubt are,—(1) continental elevation and (2) shifting of centers of precipitation and (3) modification in the composition of the atmosphere, a period of excessive ice accumulation was inaugurated. Ice finally covered immense continental areas and

from its own weight by continuous accumulation spread out (flowed) from great central areas toward the margins. There is clear evidence of interruptions or advances and retreats of this general movement many times. But the same type of work and similar results were attained in each case. The chief features of this work was the moving of rock material frozen in the ice to long distances and the deposition of it again, more or less modified by its contact with the ice or by the effect of water upon its release, at other places and with entirely new associations. The tendency to ice accumulation was finally overcome to sufficient extent for the inauguration of the present condition of things. Whether it is a permanent change or only an interglacial interval is not clear. But the ice has withdrawn to the mountains and the polar north at the present time. It has not occupied the surface of this region probably within the last 40,000 years, and perhaps for a much longer time.

5 Outline of geographic history — physiography

The surface features of a country are the result of the working out of a long and complex series of processes with and upon the materials of the rock floor or bed rock. The relationship of surface features to the formations that occur in the rock floor and their stages of development, in short, an interpretation of their origin and meaning, constitutes geographic history or physiography. It differs little in essential character from geologic history, of which it is only a special branch, i. e. the history of surface configuration. And it can not be appreciated or understood except in the light of a thorough knowledge of stratigraphic and structural geology. In individual cases or particular regions the geologic knowledge must also be specific.

a **Early stages.** Occasional glimpses of surface features, and some scattered facts about their development are to be gathered of older continental existence. Surface features characteristic of their time were developed in the great intervals between each successive period of continuous deposition. Traces of them are involved in the unconformities of the geologic column already shown in the discussion of geologic history. Hills, valleys, streams, shores and all the appropriate assortment of forms must have existed. But they could not have been like those of the present in many minor features — especially in arrangement and distribution — because the bed rock of those times had only in part reached the complexity of

structure and composition now belonging to it. Many items of importance are indicated in some of these early periods. For example, the sea encroached on the land borders repeatedly from the westward — especially throughout Palezoic times, while in Mesozoic and Cenozoic times the evidence of shiftings of sea margins is confined to the east and southeast borders, and likewise probably no near by place has been continuously beneath the sea.

But the unraveling of these conditions is obscured by subsequent events. Land surfaces that once were, became covered by later sediments. The physiography of those times, Paleophysiography, as well as paleogeography, is therefore a difficult and intricate line of investigation. With these ancient surfaces the dicussion of present features has little to do. Here and there the present surface cuts across and exposes the edges of an older one giving traces of the old profile; but in most cases it is so distorted by the foldings and other displacements belonging to a later period that a restoration of the original continental features is a task fit for the most highly trained specialist.

The surface as it now exists, and the rock floor modified only by the inequalities of the loose soil mantle, yields more readily to investigations of origin and history.

b **History of present surface configuration.** On some portions of the region there seems to have been no deposition since the close of Paleozoic time. Throughout most of Mesozoic and Cenozoic times, therefore, those regions probably have been continuously land areas (continental) and have been subjected to the agencies of erosion. This applies particularly to the Highlands region and the Catskills and the Shawangunk range and intervening country.

What the surface configuration was like in the early stages is wholly unknown. In the beginning, mountain-folding — the Appalachian folding — was in progress and the features were probably those of partially dissected anticlinal folds. With the progress of erosion the Triassic deposits were accumulated along the eastern border, probably on the continental slopes. Subsequently, further elevation extended erosion over the Triassic areas also and the Cretaceous beds were laid down on the margin. The general lines of development have been the same from that time to the present. Each successive important formation less heavily developed and forming a band outside of and upon the older one — the whole now constituting a series of successive belts the oldest of which is far inland and the newest at the sea margin.

Therefore, when long periods of denudation are referred to, it is well to appreciate that this is especially applicable to the interior, that the sea margins are comparatively new, and that certain of the inland areas were suffering erosion long before the rock formations that lie beneath and form the rock floor of the sea border districts were in existence.

Cretaceous peneplain. It appears from studies of these problems in a broad way, and, drawing upon generalizations from continental features of a much larger field than that of the present study, that the continental region of which this forms a part must, in the earlier periods, have remained in comparatively stable equilibrium for an extraordinarily long time. So long a time elapsed that most of the area was reduced by erosion to a monotonous plain (peneplain) at a very low altitude, probably not much above the sea (base level). Only here and there were there areas resistant enough or remote enough to withstand the denuding forces and stand out upon the general plain as remnants of mountain groups (Monadnocks). Possibly the Catskill mountains of that day had such relation.

This reduction of surface feature it is believed was reached in late Cretaceous time. The continent stood much lower than now. Portions that are now mountain tops and the crests of ridges were then constituent parts of the rock floor of the peneplain not much above sea level. This rock floor was probably thickly covered with alluvial deposits (flood plain) not very different in character from the alluvial matter of portions of the lower Mississippi valley of today.

Upon such a surface the principal rivers of that time flowed, sluggishly meandering over alluvial sands and taking their courses toward the sea (the Atlantic) in large part free from influence by the underlying rock structure. The ridges and valleys, the hills, mountains and gorges of the present were not in existence, except potentially in the hidden differences of hardness or rock structure. Such conditions prevailed over a very large region — certainly all of the eastern portion of the United States. This so called Cretaceous peneplain is the starting point in development of the geographic features of the present.

Continental elevation. Following upon this period of stability and extensive denudation came one of continental elevation. How much above sea level this raised the areas under present discussion may not be determined, but that it was a sufficient amount to

rejuvenate the streams and permit them to begin the sculpturing of the land in a new cycle of erosion is perfectly clear. As soon as the elevation and warping of the continental border made its influence felt in the increased activity and efficiency of the streams (rejuvenation) they began transporting the alluvium of their flood plains and to sink their courses through this loose material to bed rock. The final result of long continued denudation under these conditions in early Tertiary time was the removal of the loose mantle and the beginning of attack on bed rock (superimposed drainage). The streams formerly flowing on alluvium that had now cut down to rock found themselves superimposed upon a rock structure not at all consistent with their former courses. With the progress of erosion on this rock floor all these differences of structure, such as the differences in hardness of beds, the trend of the folds, the strike of the faults, the igneous masses, etc., were discovered and the streams began to adjust their courses to them. Valleys were carved out where belts of softer rock occur, ridges were left as residuary remnants where belts of harder rock exist, and the surface (relief) took on some of the character of present day lines. That is, the principal mountain ranges of that time were the same as those of today in position and trend; but they had not so great apparent hight because the intervening valleys had not yet been cut so deep. The principal escarpments of that time were due to the same structural lines as those of today, only they have shifted somewhat along with the general retreat of all prominences by the forces of weathering and erosion.

In the course of this work of sculpturing and the shifting of valleys and divides and escarpments and barriers into constantly greater and greater conformity with rock structure, it came about by and by that practically all of the smaller and tributary streams had so completely adjusted themselves to their geologic environment that their valleys almost everywhere followed along the softer beds (subsequent streams), the divides were chiefly of harder beds, the trend of both were almost everywhere parallel to the strike of the rock folds and other structures (adjusted drainage) This undoubtedly involved in many cases a very radical change of stream course, and in some cases an ultimate reversal of drainage to such extent that tributaries were deflected inland against the course of the master streams and in some cases actually flowed many miles in this reversed direction before finding an accordant junction (retrograde streams). At least three of the streams of

southeastern New York are still of this type — the Wallkill, the Rondout and the lower portion of the Esopus.

But the larger rivers, the great master streams, of the superimposed drainage system, in some cases were so efficient in the corrasion of their channels that the discovery of discordant structures has not been of sufficient influence to displace them, or reverse them, or even to shift them very far from their original direct course to the sea. They cut directly across mountain ridges because they flowed over the plain out of which these ridges have been carved and because their own erosive and transporting power have exceeded those of any of their tributaries or their neighbors. They are superimposed streams (not antecedent), they have, with their tributaries, settled down in the ancient plain, and, by their own erosive activity, have carved the valleys deeper and deeper, cutting the upland divides narrower and narrower until now only here and there a ridge or a mountain remnant stands with its crest or summit almost reaching up to the level of the ancient peneplain on which the work began. If the transported matter could all be brought back and replaced in these valleys the old plain might be restored, but the work would immediately begin all over again.

Of these great master streams the Hudson is the only local representative [*see* Study of the Hudson River gorge in part 2].

Tertiary incomplete peneplanation. Such processes, if allowed to continue on a stable continental region. would ultimately reduce the land for a second time to a monotonous plain (complete cycle of erosion). The beginnings of such a plain would be made in the principal stream valleys upon reaching graded condition. Their lateral planation and the development of flat-bottomed valleys would begin at about the level that the plain would stand in the final completed stage. The difference of elevation between the ridge crests or hilltops and these flat valleys, i. e. between the old peneplain and the new unfinished one would be an approximate measure of the amount of the continental elevation that instituted the new cycle.

But judging from such remnants of this later plain as are to be seen, the two, i. e. the old Cretaceous peneplain and the new Tertiary peneplain are not parallel. Toward the southeast, toward the sea, the older plain descends more rapidly than the younger and intersects it. Both pass beneath sea level in that direction. The difference between them therefore varies with locality from

o feet to perhaps 2000 feet within the borders of the area (continental tilting or warping).

Late Tertiary reelevation. Traces of such an intermediate and incomplete peneplain are to be seen in the compound nature of the large valleys of the present day. Most of them are essentially broad valleys into the bottoms of which narrower valleys and gorges are cut. The tops of the minor hills and ridges of the broad valleys represent the intermediate Tertiary peneplain that was interrupted in its development before completion (interrupted erosion cycle). The inner narrow valleys indicate that for the second time a regional elevation rejuvenated the streams and they began their work of cutting to a new grade. They have made a good beginning at this task, and as a consequence have carved some relief in the old valley bottoms. These new streams have not yet reached a graded condition.

When the glacial ice began to invade this region all of the surface features had had such a history. Leaving out of account minor fluctuations of elevation and depression, of which there may have been several of too transient character to make a lasting impression on the topography, the stages become comparatively few and the general tendencies are easily understood.

The measurable differences of elevation between the Cretaceous and Tertiary peneplains give some reasonable conception of the amount of the first continental or regional elevation. Concerning the altitude reached in subsequent regional elevation there is less certainty. None of the streams, not even the master streams such as the Hudson, reached grade, for it exhibits strictly a gorge type not only within the present land borders, but it is now known to show gorge development far beyond the present coast line. Judging from the Hudson, therefore, it seems necessary to conclude that this continental region stood at a much greater elevation in some portions of the later period than had formerly prevailed. Probably the maximum elevation immediately preceded the glacial invasion.

Conservative estimates as to the amount of elevation of that time in excess of the present would place it at not less than 2000 feet. Much more than that is believed to be indicated, possibly 5000 feet or more.

In the meantime, the master stream, the Hudson and several of the tributaries cut into their valley bottoms to such extent as to make typical gorges so deep that their beds now, since the sub-

sidence, lie much below sea level. The Hudson bed is of this character throughout its course from Albany to the Atlantic, and in the Highlands, 60 miles inland, the known rock bed at one point is more than 700 feet below sea level.

In late glacial time there was still greater subsidence (50–100 feet) than the present as is indicated by terraces above present water level and the deltas formed at the mouths of tributary streams.

Such in general outline is the history of successive conditions governing the topographic development of the rock floor. The succession of periods of stability, elevation, stability again, reelevation and subsidence have had an effect on all sorts of formations, but the extent of the impress and its permanence varies greatly in the different districts. It is not possible to study these differences in detail here. They are the minor and special local characters that are in control at particular localities. In discussions of special problems some of these are taken up in more detail. But in each case the general history as outlined above, together with the modifying influence of known local structure and stratigraphic character are the foundations of a working understanding [*see* Hudson River crossings, Moodna creek, Rondout valley, etc., pt 2].

Pleistocene glaciation. An additional modification and one largely independent of and largely inconsistent with the distribution of the smaller features of the rock floor is introduced by the glacial drift. It covers almost everything, but so unevenly as to largely destroy some of the detail. It is in places more than 350 feet thick (as in the Moodna and Rondout valleys) and in others it amounts to nothing. It covers the narrow ravines and gorges heaviest and has altered the courses of many of the smaller streams, the original channels being hopelessly buried. The result has been chiefly one of reducing the ruggedness of outline that prevailed along the newer gorges of late preglacial time.

Besides this the usual surface forms characteristic of glacial deposits, occur — the kame, the drumlin, the esker, the hill and kettle topography of the terminal moraine, the overwash plain, the delta, the lake deposit and the gentle undulations of the ground moraine. These are superimposed on the rock floor features. Both are equally important to understand in the problems that have been encountered. Which set of factors is to be most regarded in a given case depends wholly upon the locality and the kind of enterprise or work it is proposed to undertake.

c **Physiographic interpretation.** Rock floor contour is an expression of the differences in character and structure of the bed rock formations themselves, brought about by ordinary surface weathering and transporting agencies, varied in their action and effects only by certain differences in elevation above the sea. It is apparent therefore that it would be possible by careful observation of surface features to gather data sufficiently definite to furnish a basis for suggestions about hidden and hitherto unknown or undiscovered structural and stratigraphic characters. But the application of it to practical engineering problems is a complicated and difficult matter. And this difficulty is nowise simplified by the occurrence of a drift soil that tends to obscure many of the more delicate features. For example, the later narrow stream gorges marking the stage of extreme regional elevation are completely buried. Only an occasional stream like the Hudson has maintained its course unchanged and has begun excavating the channel again. But even in this case, as will be shown under a separate head, the work of reexcavation is only just begun and the amount yet to be done and the corresponding original depth of the gorge are wholly unknown.

Certain surface features, however, are readable and, considered with due regard for all possible causal factors, give very useful suggestions. From them one obtains clews as to (1) the attitude or relations of the hard and soft beds and the weak zones, (2) the dip and strike of strata, (3) the persistence of a formation, (4) the occurrence of faults, (5) the direction of the chief disturbances, (6) the resistance and durability of local rock types — in short the structural characters of all kinds because differences in the distribution of these characters have given the different topographic forms and geographic areas. They have made the features of the Highlands look different from those of the Catskills, and those of Wallkill valley different from the Croton. Because of the long train of conditions with which these surface features are each involved and the structures that they indicate they become easily the chief factors in preliminary judgment of comparative practicability of rival locations, and are the most reliable guide to direction and character and extent of exploratory investigation for many engineering enterprises.

d **Physiographic zones.** In summarizing the physiographic data it appears that the following belts or zones may be regarded as fairly distinct units:

GEOLOGIC FORMATIONS

Catskill and Oneonta sandstone conglomerates

Sherburne flags

Hamilton and Marcellus shales

Onondaga limestone

Esopus grit

The Helderberg series

Shawangunk conglomerate

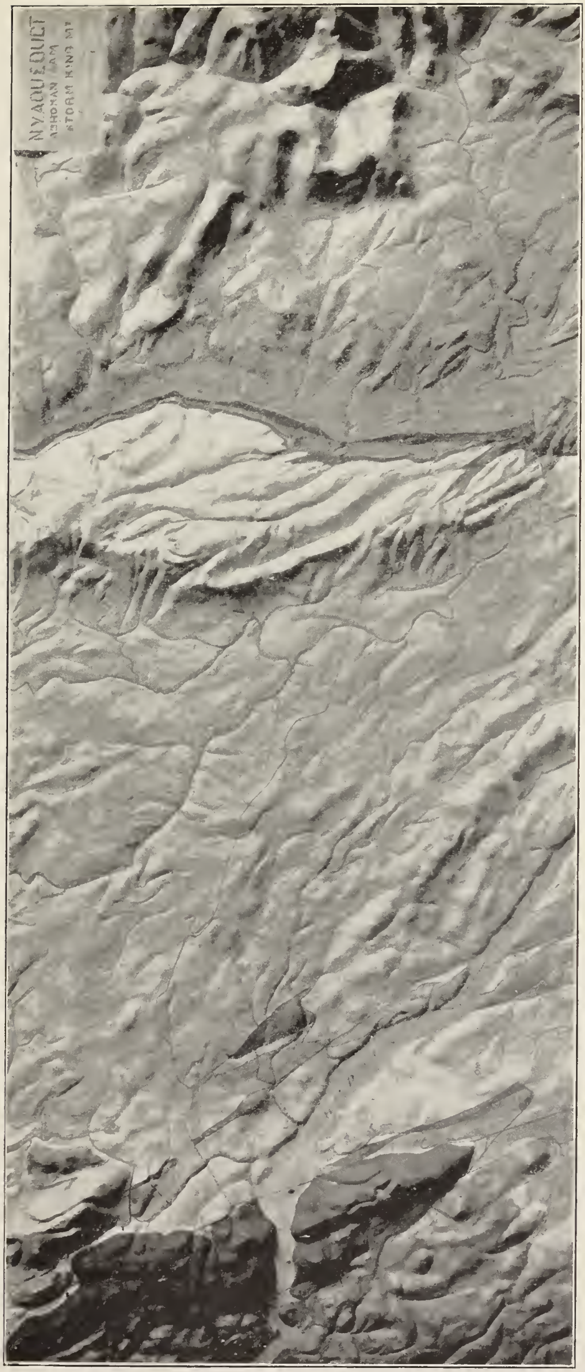
Hudson River shales, sandstones and slates

Wappinger limestone

Poughquag quartzite

torm King granite

he Highlands gneisses



The Catskill mountains

Ashokan reservoir

Hamilton escarpment

Esopus creek

High Falls

Rondout creek

Shawangunk mountains

Wallkill river

Hudson river

New Hamburg

Wappinger creek

Fishkill creek

Newburgh

Breakneck mountain

Storm King mountain

Bull mountain

Crows Nest

Foundry brook

Cold Spring

West Point

Relief map of the region from the Catskill mountains to the Highlands showing the principal physiographic features. (The original model shows also the areal and structural geology.) (Taken from model made in the physiographic laboratory of Columbia University by Messrs Billingsley, Grimes and Baragwanath)

(1) *Coastal plain.* A district underlain by Cretaceous and later rocks and confined to a part of Staten Island and Long Island, not exceeding 400 feet relief. This zone is characterized by dendritic drainage, except a narrow belt on its inner margin which is a longitudinal valley of the "inner lowland" type. Long Island sound occupies the position of this old adjusted valley.

(2) *Piedmont belt.* A district lying between the coastal plain and the Highlands. It is underlain chiefly by crystalline rocks and metamorphosed sediments. Not exceeding 800 feet relief. It is characterized by adjusted drainage obscured only by drift. The ridges and valleys trend northeast and southwest close together and with very little variation on the east side of the Hudson, while on the west side the gentle dips of the Triassic give broader and more unsymmetrical forms with dip slopes and escarpments wholly independent of the opposite side. The zone is essentially transitional between the simple forms of the coastal plain and the complex mountainous character of the Highlands.

(3) *Highlands.* The rugged elevated zone formed by the crystalline gneisses. Reaching elevations of 1600 feet. It is characterized by irregular mountain masses and lofty ridges of a general northeast trend but with many prominent irregularities both of form and of drainage. The valleys are deep and narrow. There are many steep escarpments. It is a mountainous zone in which complex structures and rocks have led to the development of complex forms. The zone forms a sort of barrier 20 miles wide across the Hudson river which exhibits its most zigzag and narrow and gorgelike development in this district.

(4) *Appalachian folds.* Characterized by folded Paleozoic rocks north of the Highlands. Reaching elevations of 1500 feet rarely — general relief 400–800 feet. North of the Highlands the relief is much less pronounced. The softer rocks of the early Paleozoic formations permitted the development of a broad valley with almost perfectly adjusted tributaries, most of which on the west side of the Hudson are reversed. The topographic forms give expression to the universal folding and faulting of the formations. It is essentially a transition from the complex mountain zone of the Highlands to the much simpler Catskill area.

(5) *Catskill Monadnock group.* Characterized by undisturbed Paleozoic strata and very strong relief — reaching elevations of 3500 feet. The eastern margin is an escarpment facing the Esopus and Rondout valleys which are adjusted to the gently dipping strata of that side. Over the rest of the district the beds lie so

flat that drainage is essentially dendritic modified slightly by jointing. The great relief of the Catskills is due wholly to erosion of flat but very resistant strata that withstood the destructive erosion of Cretaceous peneplanation and stand as residuary remnants even to the present time. The Catskills are therefore essentially a Monadnock group. In structure they are almost as simple as the higher portions of the cuesta of Long Island, and they hold the same relation to the forms developed by erosion out of the old Paleozoic coastal plain of the interior.

Summary

Physiographically the most complex zone is midway in the region under discussion — i. e. The *Highlands*. This belt is bordered on both sides by less complicated zones of less relief, of more regular topographic forms and less obscure history — the *Piedmont zone* on the south and the *Paleozoic folds* on the north. The outer margins are both simple, essentially eroded coastal plains with strata dipping away from the central belts and on which forms and drainage lines characteristic of such history are developed. These outer zones are the *coastal plain* of Long Island on the south and the *Catskill Monadnock group* on the north. It matters little that they differ in age by almost half of the known geologic column.

A view of the Catskill mountains looking across the Beaverkill basin which is to form a part of Ashokan reservoir

II

GEOLOGIC PROBLEMS OF THE AQUEDUCT

INTRODUCTION

The group of studies assembled in this part are chiefly those that have required considerable exploratory investigation in connection with the proposed Catskill aqueduct and that have furnished new data of a geologic character. In some cases the additional investigations have discovered new and wholly unknown structures or conditions and in all cases the features as now established are much more accurately known than would otherwise have been possible.

The benefits of the studies have been twofold and reciprocal. On the one side the practical planning of the enterprise has constantly required an interpretation of geologic conditions as a guide to locations and methods and on the other the extensive investigations carried on have given an opportunity for practical application of geologic principles under conditions seldom offered and the data secured in additional explorations serve to make the detail of some of these complex features now among the most fully known of their kind. Examples of such cases are (*a*) the series of buried preglacial gorges (as in the Esopus, and Rondout and Wallkill and Moodna valleys) and (*b*) the completed geologic cross sections (such as the Rondout valley, the Peekskill valley, Bryn Mawr, etc.) and (*c*) the numerous additions to the knowledge of local rock conditions (such as that at Foundry brook, Rondout creek, Coxing kill, Pagenstechers gorge, Sprout brook, and others).

Almost every locality has its own specific problem and its own peculiar differences of treatment and interpretation of features. Nearly all of the studies here presented came to the attention of the writer and others[1] in the form of definite problems or questions involving an interpretation of geologic factors and an application to some engineering requirement. Some of these questions, as is pointed out more fully in part 1, chapter 2, are (*a*) the location of

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[1] Professor James F. Kemp of Columbia University and W. O. Crosby of the Massachusetts Institute of Technology and the writer constituted the regular staff of consulting geologists.

buried channels beneath the drift, (*b*) the character and depth of the drift, (c) the kind of bed rock, (*d*) the condition of bed rock for construction and permanence of tunnel, (*e*) the underground water circulation, (*f*) the occurrence of folds and faults, (*g*) the position of weak zones, (*h*) the depth required for substantial conditions, and many other similar problems.

These need not be treated in their original form. Indeed many of them have now ceased to be problems in any real sense, for subsequent provings have made them simple facts, and wholly new questions came to take their places. In some of the larger problems, however, it is believed that a treatment which involves a discussion of the original problem and the method of solving it, together with the data thus secured and the final interpretation of geologic features as now understood or established will be more instructive than a mere enumeration of the collected results.

So far as possible each problem is treated as a unit and fully enough to be understood by itself. But a general knowledge of local geology as outlined in part 1 is assumed.

CHAPTER I

GENERAL POSITION OF AQUEDUCT LINE

Surface topography constitutes the chief factor in determining the general course of the aqueduct. It is planned to control the water so that it will flow to New York city. There is therefore a gradual descent of aqueduct grade from 510 feet A. T. at Ashokan dam to 295 feet at Hill View reservoir. Wherever the surface of the country is approximately the same as the aqueduct grade for that district it permits of the so called "cut and cover" type of construction which is much cheaper than any other. Therefore, other things being equal, the position that will permit the greatest proportion of cut and cover work would have a decided advantage. So it is possible from any series of good topographic maps to lay out trial lines that are sure to be worthy of consideration. The topographic sheets of the United States Geological Survey and the maps of the New York Geological Survey are of great usefulness in such preliminary work.

But a little field examination shows that there are many other features and conditions that materially modify even comparative cost and are still more important factors in consideration of permanence and safety. Sometimes it is not apparent that a course has any objectionable features till considerable exploratory work has been done. Likewise a serious difficulty at one point may more than counterbalance advantages at some other, so that considerable portions of the line are finally shifted to a better average position. In the course of these preliminary explorations much valuable data have been secured that now relate to points a considerable distance off the present line. The information has, however, been necessary and useful.

One of the cases of this kind where geologic conditions have had an almost controlling influence is involved in the choice of place of crossing of the Hudson river. It has involved a shift of the whole line between the reservoir and the Highlands. Difficulties encountered in finding a crossing of the Esopus also contributed to the argument favoring a shift of the line [*see* map of trial lines west of the Hudson]. One of the points where exploratory work had reached definite results before the more southerly line was finally adopted is near West Hurley. Here wash borings

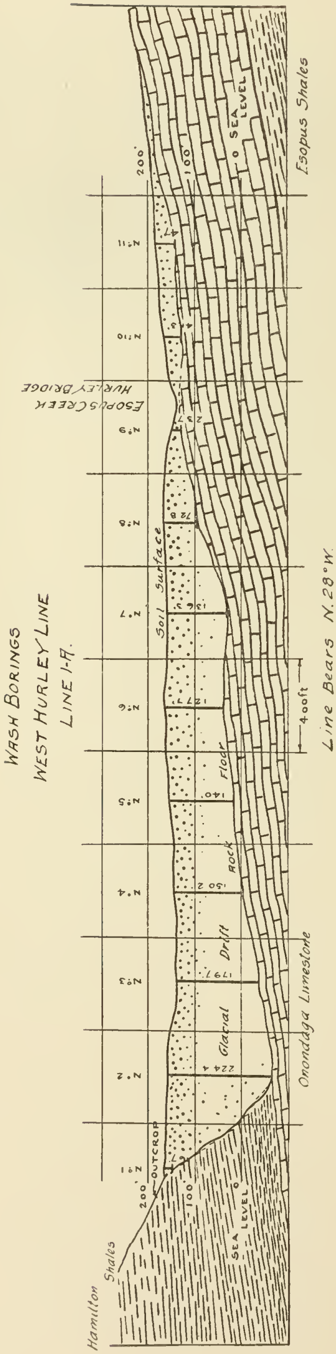

Fig. 7 Geologic cross section of the Esopus valley at West Hurley as indicated by a series of wash borings

were successfully put down throug the fine sands and silts of th lower Esopus valley so as to giv a fairly acceptable profile of th rock floor [*see* fig. 7]. Esopus cree in this portion of its course follow the Hamilton shales escarpmer which forms a steep border on th west side, while the east border o the valley and floor are forme by the underlying Onondaga lime stone. Gentle westerly dips preva for both formations, so that in th perfect adjustment reached befor the glacial invasion a cross sectio would have shown a typical unsym metrical valley—one side a gentl dip slope and the other a bluff de veloped by the undercutting of th stream as it shifted against th edges of the shales.

Results of exploration show tha the valley is filled to a depth o more than 200 feet with silts an sands that are essentially overwas and glacial lake deposits. The fla surface further favors this explana tion as had been pointed out befor any explorations were made. Late observations in that portion of th Rondout valley which is a continu ation of this structural feature indi cate similar deposits as far sout as the new line at Kripplebush, 10 miles away.

In this instance at West Hurle by careful measurement of dips o the Onondaga limestone and th Hamilton shales it was possible t estimate the approximate depth t which the Onondaga floor rocl would pass by the time the base o

he escarpment is reached. It was further believed that the cov-
red portion is wholly drift-filled down to the Onondaga. It was
asy therefore to estimate the approximate profile and suggest the
oint of greatest probable depth. The accompanying figure illus-
rates the form and structure of this valley. Each valley has had
n a smaller way a similar study and adjustment of location of line.

The final result is shown on the accompanying map which indi-
ates the course of the aqueduct as now being constructed.

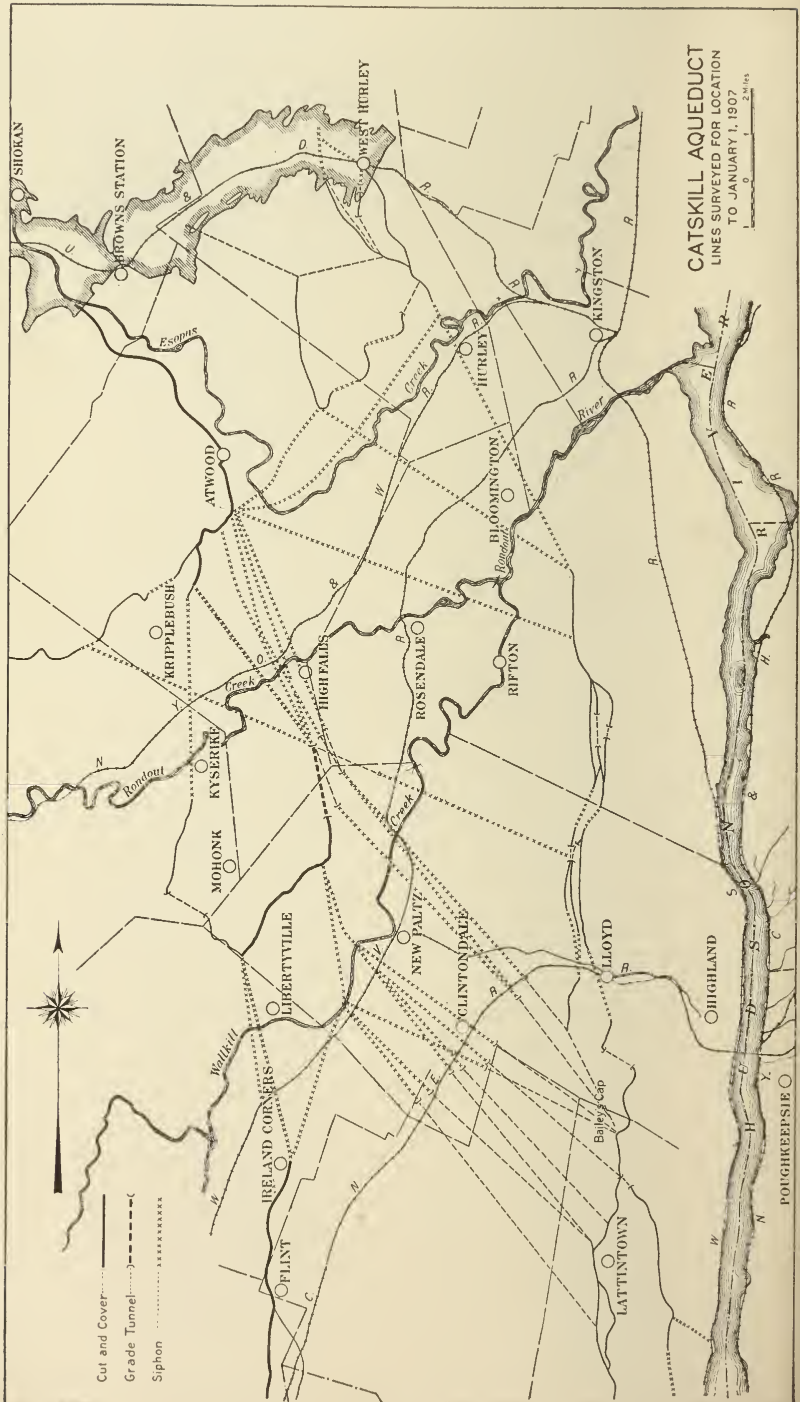

Fig. 8 Location map; showing lines surveyed for possible location and final line selected with its different types of construc-

CHAPTER II

HUDSON RIVER CANYON

This is a special study of the Hudson river gorge[1] based upon explorations by borings at the several proposed crossings. Altogether 226 preliminary borings were made on 14 cross sections. The most important lines of borings are located at seven different points on the Hudson [*see* location map]. Four of them are in the vicinity of New Hamburg, lying not more than a couple of miles north and south of that village, while three others are located within the Highlands. [*See* comparative geologic study in following chapter.] The chief basis of information on all but one of these lines is the wash rig, a contrivance as already pointed out that gives rather incomplete data [*see* Relative Values of Data, pt 1]. On this account it is not possible to give the true bed rock profiles of the river canyon even approximately except at one location, i. e. the Storm King–Breakneck mountain line. An occasional diamond drill hole has been put down on some of the others and this has been done systematically at the Storm King location in a persistent effort to determine the gorge profile and bed rock condition.

The work already done has proven that in the Hudson at least the wash rig borings give wholly unsatisfactory profiles. The holes do not penetrate the boulders and heavy glacial drift that is now known to fill the canyon. The profiles, however, that were drawn from this sort of data have some value. They indicate that bed rock is still lower and that the finer silts extend down to these depths. In some places there is a heavier filling of 400 to 500 feet below them before the rock floor is reached.

Wherever the diamond drill has succeeded in reaching rock the formational identification has been made and the geological cross section is a little more complete. As a matter of fact, however, at almost every locality the structural relations are so complex or so obscure that they are still not fully known. The accompanying profiles and cross sections summarize the mass of accumulated data:

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1 Kemp, Prof. J. F. Buried Channels beneath the Hudson and its Tributaries. Am. Jour. Sci. Oct. 1908. 26:301-23. Some of the accompanying descriptions of river crossings follow closely this excellent summary of Hudson river explorations from Professor Kemp.

Fig. 9 Key map showing the locations of lines of wash borings forming the basis of the accompanying cross sections of the Hudson above the Highlands

1 Points of exploration[1]

a **Tuff crossing.** This line is a half mile above Peggs point. Wappinger limestone forms the east bank of the river and Hudson river slates the western bank. There seems to be no abnormal structural relation of the formations. All data are from wash borings. The accompanying section gives the results.

b **Peggs point line.** Peggs point is 2 miles north of New Hamburg. At this location Wappinger limestone forms the east bank and Hudson river slates the west bank of the river as in the previous case. The limestone dips gently westerly while the slates have a variable attitude. This is a normal relation and there is no direct evidence of any great structural break. A large number of wash borings have been made and five diamond drill holes were driven, three of them in the river. None indicate a greater depth than 223 feet, although there is a wide stretch, 1040 feet, not explored by the diamond drill. This space must contain the deeper gorge if one exists here. From the known conditions at the entrance to the Highlands, 10 miles further down stream, where the channel is known to be more than 500 feet deeper, it may be rather confidently asserted that a deeper inner channel does exist at this point.

c **New Hamburg line.** This line crosses the Hudson from Cedarcliff to the village of New Hamburg. The river is narrow — only 2300 feet. There are no drill borings within the river channel, but there is one on each bank. Both penetrate Wappinger limestone first and then pass into Hudson river slates beneath. How much of a gorge exists here is wholly unknown except in so far as may be judged from the wash boring. There are the same reasons for believing that a gorge exists as those noted for the Peggs point line.

Structurally this line is probably the one of greatest complexity. It is however perfectly clear that the abnormal position of the slates and limestone on the east side of the river is caused by a thrust fault. A similar relation of the slates and limestone on the west side must be due to a like movement, but whether they are separated portions of the same structural unit or of two adjacent ones is not clear, although they are probably distinct

[1] All of these explorations on the Hudson river have been under the direct supervision of Mr William E. Swift, division engineer, in charge of the Hudson River division.

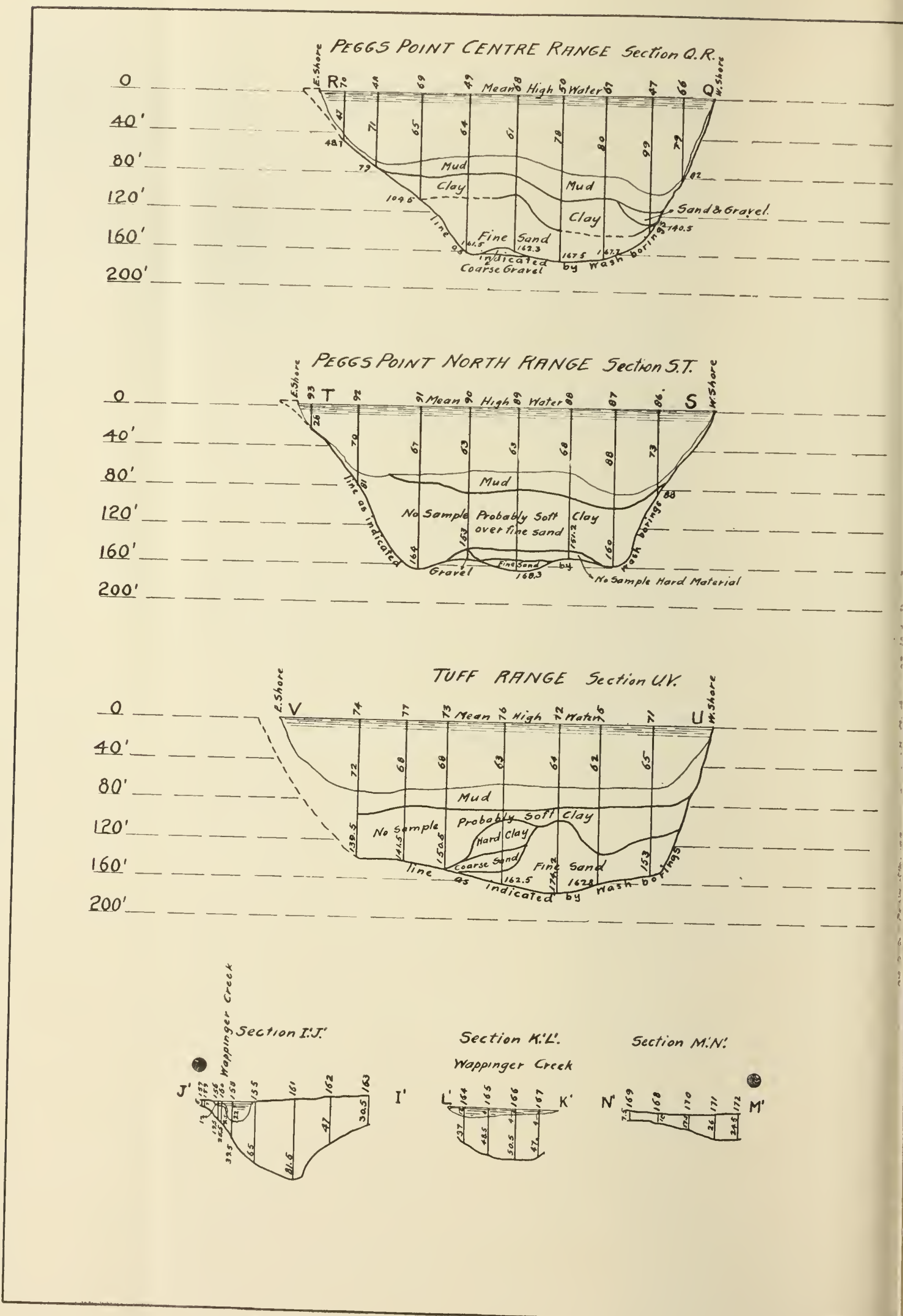


Fig 10 Cross sections of the Hudson river north of New Hamburg and of Wappinger c[reek] based upon wash borings. [For locations *see* key map, fig. 9]

Five lines of wash borings were followed, and the results of these are indicated in the accompanying figures. A maximum depth of 263.5 feet is shown by these wash borings.

d **Danskammer line.** This line is about a mile south of New Hamburg. Two lines of wash borings were made, reaching a maximum depth of 268.5 feet. In this case slates standing almost vertical form the east bank and limestone dipping gently eastward the west bank of the river. Whether there is a deeper gorge or a more complex structure here is wholly unknown.

Of the three remaining lines, all of which are within the Highlands, that one projected between Storm King mountain on the west and Breakneck ridge on the east has been much the most thoroughly explored. It is known as the Storm King line. The other two have seemed to merit less attention. One crosses the river from Crows Nest mountain to Little Stony point and Bull mountain just north of Cold Spring, and is known as the Little Stony point line. The other crosses at Arden point about a mile south of West Point and Garrison.

e **Arden point line.** Only wash borings were made. A maximum depth indicated by this method is 220 feet. Structurally this location appeared to have disadvantages, and although the evidence as to bed rock conditions is confined to the natural outcrops, there is no doubt but that it has objectionable features of this sort.

The Hudson follows closely the structural control in this portion of its course. These structural elements include the foliation, the bedding of the original sediments, the subsequent shearing zones, and the strike of folds and faults. Crushed and sheared zones are nowhere in the Highlands seen so extensively developed as on the islands and the east bank of the Hudson in this, the central portion of its Highlands course. The river is very narrow, being only 2120 feet on this line.

f **Little Stony point line.** The river here is 2360 feet wide. The rocks on each side are similar and give no clue to possible depths of channel. Less than 200 feet was reached by the lines of wash borings. Three drill borings penetrated the stony or bouldery river filling somewhat deeper — one near the center reaching 322 feet. None, however, reached bed rock.

g **Storm King crossing.** Extensive exploratory work has been carried on at this point, both on the banks and in the river. Wash borings as usual have given poor results. Two diamond drill holes were run at an angle toward and beneath the margins of the

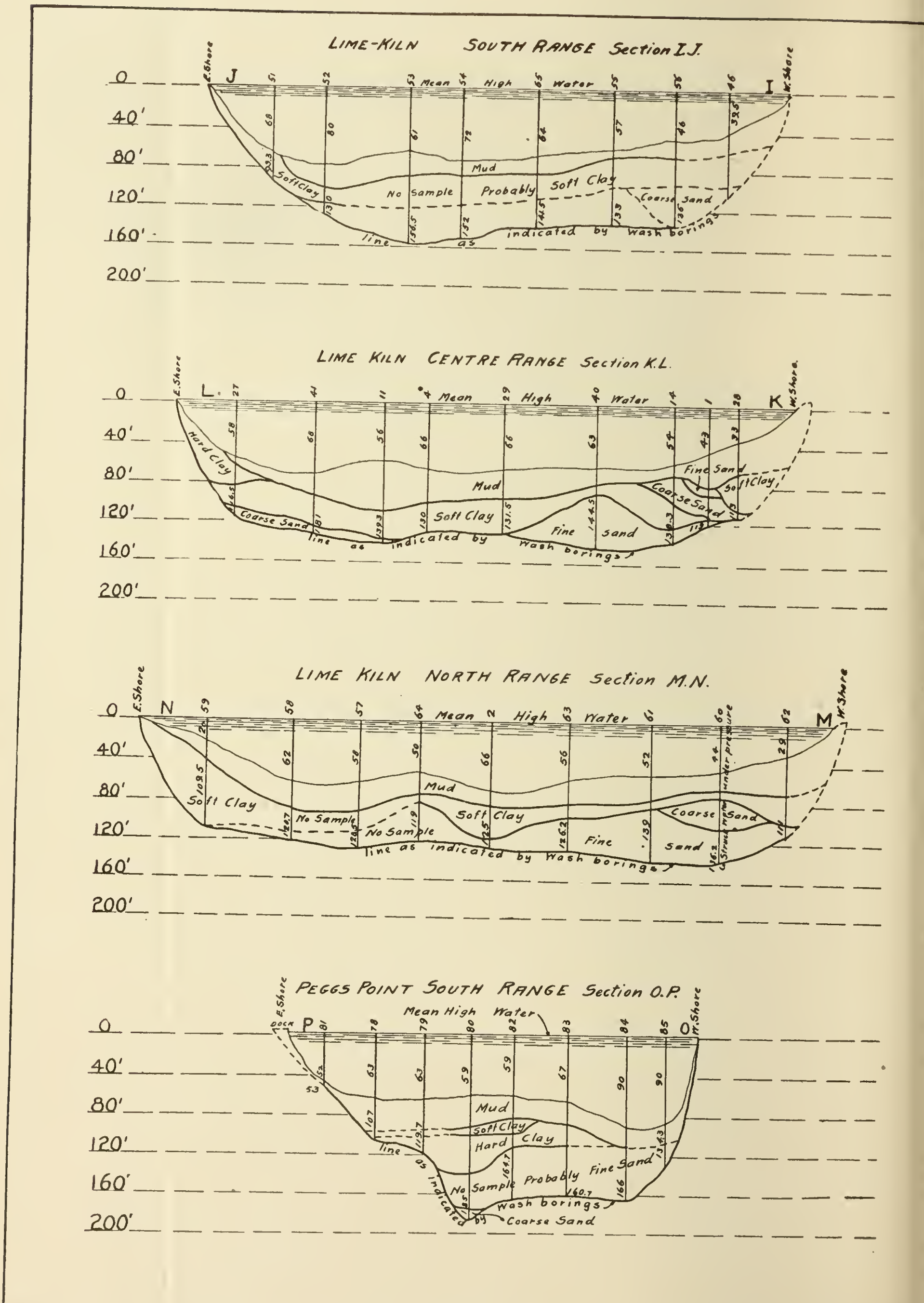


Fig. 11 Cross sections of the Hudson river near New Hamburg based on wash borings [For locations *see* key map, fig 9]

river, and in addition a working shaft suitable for permanent use has been started on each side of the river. These have thoroughly explored the rock character to a depth of about 800 feet. It has proven to be of constant type, a gneissoid granite, affected by moderate amount of jointing, shear movements and occasional dike intrusion. The two sides are alike, the rock in depth is comparatively free from water, nearly all coming from the adjacent surface drainage.

Persistent efforts have been made to use the drill in the river to explore the rock channel, but with meager results. The difficulties to be overcome in drilling in this tidal river to the necessary depth are probably greater than have even been encountered in any similar undertaking. The disturbance presented by the current, the tide, the depth of water, the drift filling above the rock channel, and the traffic in the river are a constant menace. The complex character of drift filling in this gorge, especially the occasional heavy bouldery structure, makes it necessary to reduce the size and recase the holes repeatedly. But in this regard the work has suffered less actual loss than by the menace of river traffic. Several times after the greatest efforts had been put forth in pushing the drills deep into the gorge a helpless or unmanageable or carelessly guided steamer or scow has wrecked the work. In this way some of the most critical locations have been lost together with many months of labor.

The results are shown on the accompanying drawings.

It is worth noting that of those holes located far out in the river channel only two have reached bed rock. Even these two have penetrated the rock so little distance that there might be still some doubt of permanent bed rock. The fact, however, that the rock found is of the right type, i. e. like the walls of the gorge, leads to the conclusion that the bottom was actually penetrated. Neither of these holes are in the middle of the river, and, although the maximum depth of 608 feet was reached by one of them, the central portion of the buried channel proves to be still deeper. One hole located near the middle was able to penetrate to a depth of 626 feet without striking bed rock. But it was finally lost. The latest results are from a boring that has reached a total depth[1] (January 1, 1910) of 703 feet, the last 8 feet of which was believed by the drillers may be in bed rock. All above is drift and silt.

[1] Subsequent exploration has proven that the bottom of the old channel lies still deeper. This boring has been pushed to a depth of 751 feet without yet touching bed rock (Oct. 8, 1910).

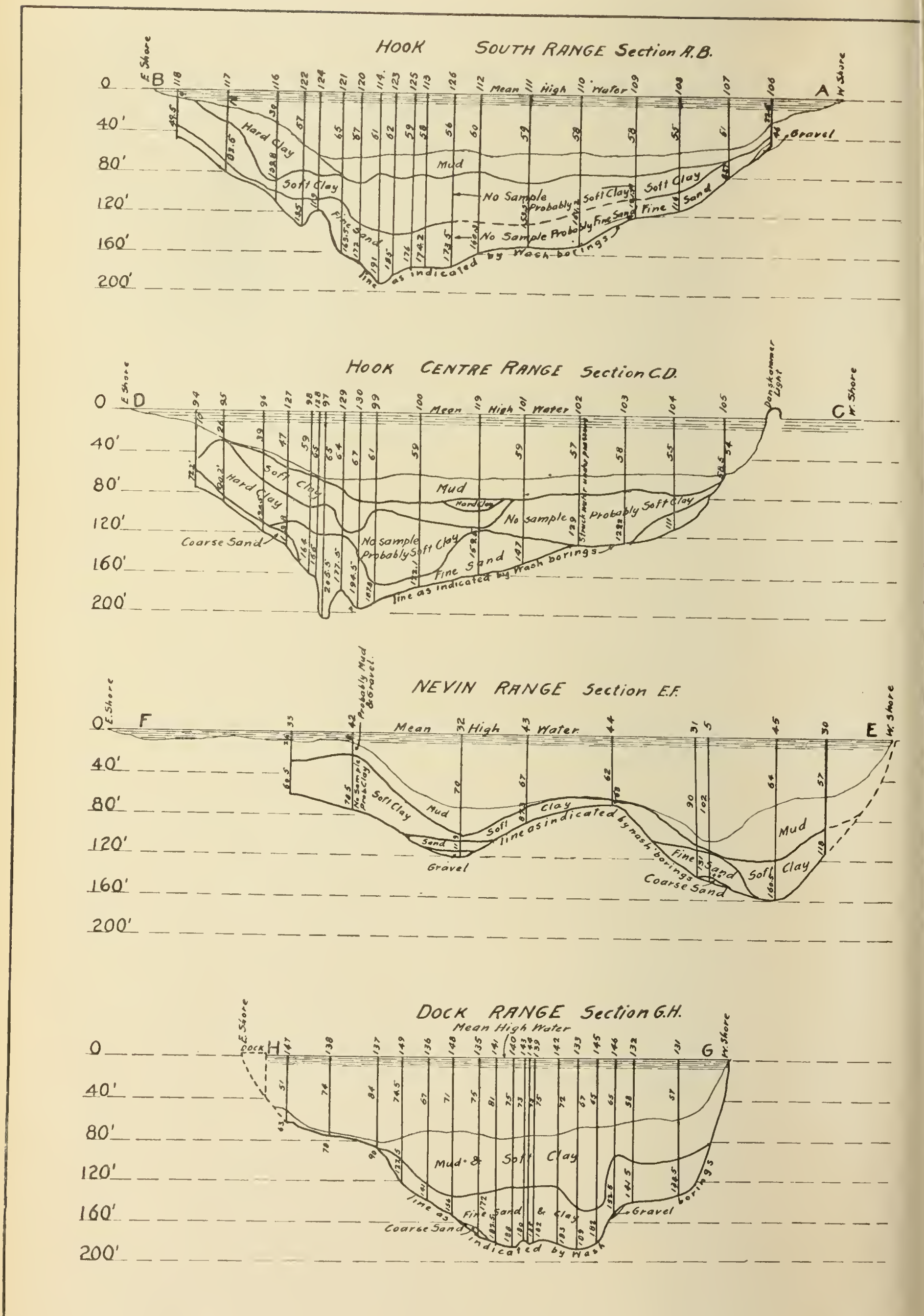
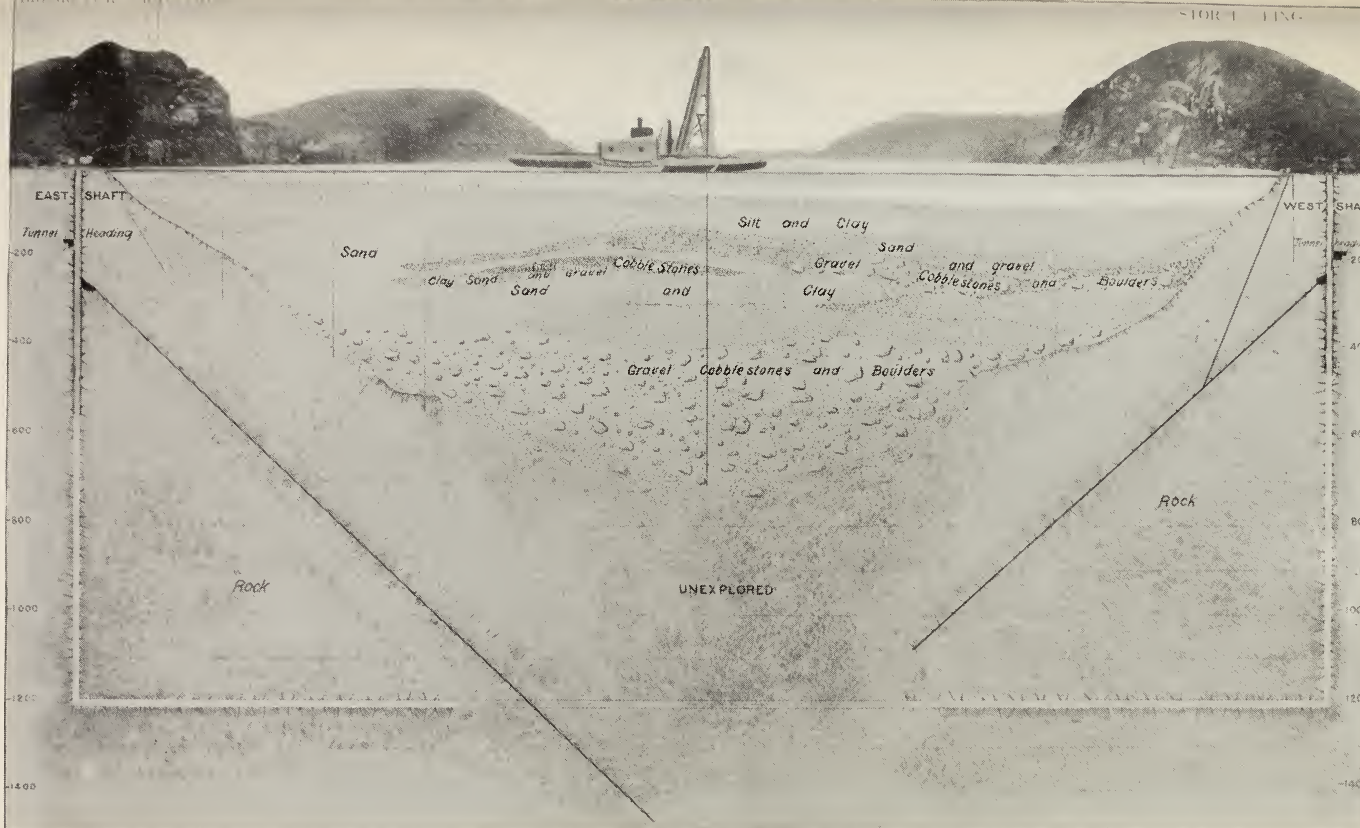


Fig. 12 Cross sections of the Hudson river at four points between Danskammer Light an[d] New Hamburg [*see* key map, fig. 9, for locations]



A composite diagrammatic cross section of the Hudson gorge at the Storm King crossing showing the method of making the vertical borings, the direction of the first two inclined borings, the positions of the shafts and the extent of explorations. (Adapted from drawings of the Board of Water Supply)

2 Discussion

The present facts therefore indicate that the buried Hudson channel is more than 700 feet deep between Storm King and Breakneck ridge. Furthermore this is more than twice as great depth as has been found (so far as yet tested) at any other point either above or below this place. Although data of this kind are scarce yet there are two other borings that have given surprising results —(*a*) at Peggs point and (*b*) the Pennsylvania borings at New York city.

Peggs point. At this place, where studies were made for a possible crossing, a hole 700 feet from shore struck rock at 223 feet and the unknown space or interval within which it is possible for a channel to lie is less than 1040 feet wide. This is about 10 miles above the Storm King crossing and in much softer rock (Hudson River slates). Yet the Storm King gorge in granite is deeper than that (deeper than 223 feet) for a width of nearly 2500 feet. Of course, there may be, and probably there is, a much deeper channel at Peggs point within the 1040 feet unexplored space. But even so there is a remarkable discrepancy in width of gorge at these two points that must be accounted for in some other way than simple stream erosion.

The Pennsylvania borings opposite 33d st., New York city. The data gathered by the Engineers of the Pennsylvania Tunnel Company in their explorations for tunnel from 33d street, Manhattan, to Jersey City, have recently been made public. There are six holes into rock. Their positions and depth to rock bottom are given below:

a 800′ from New York bulkhead 190′ to bed rock = aplite

b 1000′ from New York bulkhead 290′ to bed rock = hornblende schist

c 2180′ from New York bulkhead 300′ to bed rock = chloritic and serpentinous rock.

d 2350′ from New York bulkhead 260′(?) to probable boulder = jasper breccia

e 3300′ from New York bulkhead 270′ to bed rock = arkose sandstone

f 13700′ from New York bulkhead 225′ to rock = brown sandstone

There are other shallower borings on both sides of the river. Those on the Manhattan side are represented by several different facies of Manhattan mica schist and granite and pegmatite in-

trusives, while the New Jersey side is represented by differen[t] varieties of arkose and gray and brown sandstone belonging to th[e] Newark series.

It should be noted that although only one hole marks rock bottom as low as 300′ (that one situated 2180′ from the New York bulkhead about the middle of the river), yet there is at least a 1100 foot space on each side which is essentially unexplored, and within one of these spaces there may be a deeper gorge.

The cores taken from the east side of this middle zone belong to facies of the Manhattan schist formation, while those on the west side belong to the Newark series. The middle one, however, is essentially a soapstone or serpentine and may be a continuation of the Hoboken serpentine belt. In any case, it belongs in age to the older series of formations.

It is certain that here again, 50 miles below Storm King locality, a very deep gorge, if one exists, must be comparatively narrow.

Submarine channel. It is worth noting in this same connection that a submerged gorge has been mapped by the Coast and Geodetic Survey on the continental shelf from the vicinity of Sandy Hook to the deep sea margin, a distance of more than a hundred miles. This is interpreted by Spencer[1] and others with apparently sound argument as the lower portion of the old preglacial Hudson gorge formed during an epoch of great continental elevation. The outer portion of this submerged gorge is very deep. That section near shore is shallow and obscure. It has been assumed that this obscurity and shallowness is due to offshore and river deposition, filling the channel with silt. No better explanation is yet forthcoming. But even here the width of the submerged gorge is suggestive. In very much softer sediments than any encountered in its whole course on present land, and in a part of its course from 50 to 100 miles below the other sections, the river has cut a gorge only 4000 feet wide at top and 2000 feet deep within a broader valley 5 miles wide. In its deepest known part the proportions are 10,000 feet in width at top to 3800 feet in depth.

From this it would appear that the inner gorge type of development is characteristic of the Hudson, and that it was originally an exceedingly narrow one compared to the present river width, indicating rapid erosion during a brief and comparatively recent epoch. This submerged continental margin condition is favorable to the

[1] Spencer, J. W. The Submerged Great Canyon of the Hudson River. Am. Jour. Sci. 1905, v. 19.

Plate 15

The enlargement of the Hudson river known as Newburgh bay as seen from the northerly slope of Storm King mountain. This shows the gathering ground of the tongue of glacial ice that enlarged and overdeepened the Hudson gorge at the Gateway. (Photograph by Board of Water Supply)

assumption that there are narrower, still deeper channels within the unexplored spaces both at New York city and at Peggs point.

The only known exception and the one really surprising section is the Storm King crossing. It is too wide, considering the profiles at Peggs point and at New York city for simple normal stream erosion. That is clear enough. But a still more difficult question is whether it is also too deep. It is much deeper than any known section above or below for a distance of 50 miles.

There appears to be only one satisfactory explanation of this abnormal width of the deeper section and that is by glacial erosion. Just above Storm King is the wide bay opposite Cornwall and Newburgh. The few glacial scratches observed trend about s. 15° e. The ice therefore moved to the east of south, and it is noted that the course of the river is about the same. The northern front of Storm King mountain is steep and trends east and west while the northern front of Breakneck mountain trends southwest. It would appear therefore that these slightly converging mountain fronts served as sort of a funnel into which the ice was forced from the wide gathering ground immediately above, and through which there may have been a tongue or stream of ice of more than average power and efficiency moving almost in direct line of the present course of the river. It is reasonable to expect that these conditions would favor more than average glacial erosion.

3 Storm King–Breakneck mountain profile

It is practically impossible to draw a complete profile for the Hudson river gorge at any point in its lower course. Even at Storm King mountain or New York city or at Peggs point, at each of which places considerable exploratory work has been done, only the broadest features are known. Nevertheless, several things have been proven and they are worth considering in this question. They may be summarized as follows:

a If there is a very deep gorge at Peggs point (deeper than 250 feet) it can not be over 1000 feet wide.

b If there is a very deep gorge at New York city (deeper than 300 feet) it can not be over 1200 feet wide.

c At Storm King, located between the other two and in harder rock than either of them, a gorge at least 400 feet deep is proven to have a width of more than 1500 feet.

It is certain that simple stream erosion could not account for such a difference of cross section. There is no doubt but that en-

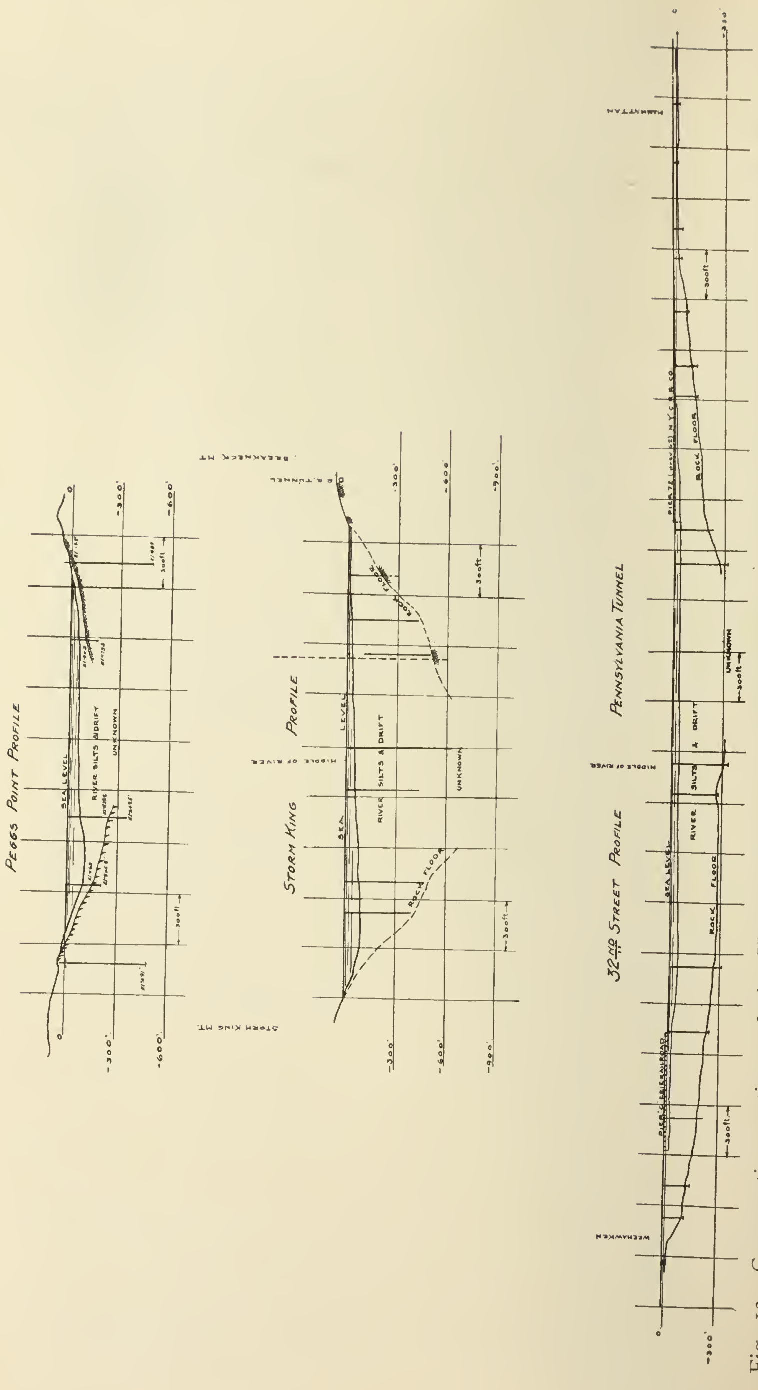


Fig. 13 Comparative sections of the Hudson gorge — at Peggs point, at Storm King and at 32d street, New York city — drawn to the same scale to show the remarkable size of the Storm King section below 300 feet

larging by ice so far as widening is concerned is practically proven. It may also be overdeepened, by which is meant that it may have been gouged out deeper than could have been done by a stream of water alone.

If ice action then be granted, the profile ought to be and probably is essentially an ice valley profile, i. e. of a more or less U-shape, rather than of typical stream erosion form. It is certain also in this case, if glacial overdeepening is admitted, that there can be no stream notch in the bottom of it. The significance of this lies in the probability that the floor is approximately the same level on a considerable portion of the bottom, so that when once the margin of this floor is touched the gorge as a whole is thereby determined for depth.

After plotting the borings data and relying upon the factors that seem to be most firmly established, it appears that the following statements are as definite as the facts will warrant:

a The average slope of the Storm King side of the valley above river level is nearly 38°, and this is in several steps or sections of steeper and flatter slopes. The Breakneck side is about the same.

b The average slope of the Breakneck side of the gorge below present water level (the side on which alone there are enough data to plot a fairly good curve) does not vary much from this same value [*see* accompanying profile]. And it is also in steeper and gentler slopes, apparently a series of U-shaped forms set one inside the other, each inner one deeper than the next outer one. Each successive inner step is approximately 300 feet deeper than the last and 1000 feet narrower.

It is certain that this sort of profile is not as simple as at first appears. The surprising feature is the close approximation of the slopes above and below present river level. In view of the fact that glacial widening has been practically proven, as shown before, not much importance can be attached to this uniformity or similarity of slope. Ordinarily such a persistence of slope would be taken to indicate simple stream origin, but having abandoned that hypothesis, the value of the angle as a factor in estimating probable total depth is lost. In short, one can not assume that the deepest point is indicated by the intersection of the slopes of the two sides.

But there is one feature that is at least suggestive. That is the uniformity of the succession of steps and slopes. It was noted above that each successive inner one is about 300 feet deeper and 1000 feet narrower. If this uniformity and proportion is main-

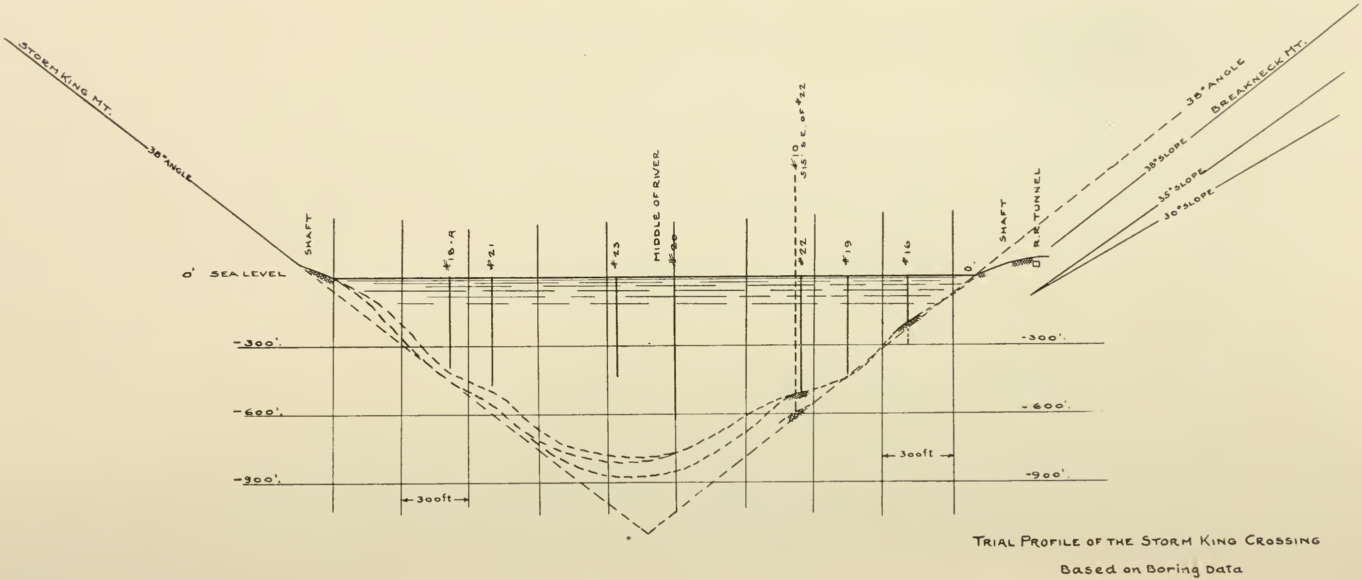


Fig. 14 A study of the Hudson gorge profile showing location and depths of the principal borings. The tendency to U-shaped forms, one within the other, is believed to be indicated by the borings on the Breakneck mountain side and give a suggestion of the probable depth of the innermost form.

tained for the next inner one — inside of holes no. 10 and no. 22 — there would be room for only one more and its approximate depth would lie somewhere between 800 feet and 900 feet below tide.

Recent drilling has shown a marked difference between holes no. 10 and no. 22. Hole no. 10 located 500 feet southeast of no. 22 is nearly 100 feet deeper. Since no. 10 is nearly straight down stream this discrepancy is disturbing. But if one considers the distance of each from the east bank it is noted that no. 10 is 900 feet out and no. 22 is 800 feet. Hole no. 10 is thus about 100 feet nearer the middle of the stream and allowing for this additional distance according to the profile as known it ought to be at least 70 feet deeper than no. 22. This corrected difference then of 30 feet does not seem to be of much importance.

Summary. Everywhere in its lower course the Hudson exhibits the character of a narrow gorge, sometimes of a gorge within a gorge, most of which is either submerged or buried several hundred feet.

Depths of 200 to 300 feet are average and for the last 60 miles of its course represent widths of 1000 to 3000 feet.

Greater depths are believed to be maintained continuously within a narrower inner notch, but of this there is no conclusive proof and very little evidence outside of a few Storm King borings.

The Storm King-Breakneck notch is over 751 feet deep. But it is abnormal at least in width and probably also in depth, due to ice erosion.

The conditions indicate (*a*) rapid stream erosion while the continent stood much higher than now, (*b*) glaciation which enlarged the gorge in at least a few places and filled it with rock debris and later with mud during submergence, (*c*) finally an emergence with minor oscillations and erosion to the present time.

4 Origin of the present course of the Hudson

The course of the Hudson is in most respects no more abnormal than that of the Susquehanna. Both flow across mountain ridges in such manner as to indicate their superimposed character. Both date back to the Cretaceous peneplain. But the striking feature of the Hudson is its straight course. As Hobbs and others have pointed out, the river is abnormally straight for more than 200 miles — and this in spite of the fact that it crosses the bedding and other structures of the country rock at nearly all points at an

oblique angle. Such conditions are especially notable south of the Highlands where the Hudson cuts at a low angle across the ends of a succession of complex folds of the crystalline metamorphics for 30 miles to New York city. But this is true only of the east side of the river. The west bank is an almost unbroken uniform escarpment of the Palisade diabase intruded sheet underlain by Newark sandstones, which if laid down upon a pretty well planed Pretriassic surface might easily control the Hudson, and which would not differ from its present course.

The most evident exception to this is the course of the river from Hoboken to Staten Island. Instead of following the line of contact between the crystallines and Triassic formations, the river cuts through the crystallines leaving large masses of serpentine and associated schist on the west side. This together with the behavior of the river in cutting across the strike farther north near the Highlands is believed to strongly favor the fault theory of location especially south of the Highlands. The same conditions would be favorable to the development of a narrow gorge and perhaps a very deep one rapidly eroded along the crush zone of the fault.

From the northern entrance to the Highlands to Haverstraw bay, where the Palisades are reached, the stream course is not by any means straight, but shifts from longitudinal structure to cross structure alternately in a zigzag manner. North of the Highlands the course is more direct again. On the whole the present explorations have added little to the facts bearing upon this question. Faults crossing the river are common and easily recognized. Occasionally one appears to pass into the river gorge at a very small angle and not reappear. In a few places, especially in the Highlands, the course does not seem to be consistent with the hypothesis of a large fault line. It is to be expected that further work at the Hudson river crossing will add materially to the facts relating to the structures within the gorge.

CHAPTER III

GEOLOGICAL CONDITIONS AFFECTING THE HUDSON RIVER CROSSING

General statement

This is essentially a study of the geologic features and conditions shown by exploration to have an important influence upon the choice of river crossing for the aqueduct. In the beginning it was possible to consider that any point between Poughkeepsie and New York might furnish a crossing. The early preliminary investigations showed that it would be desirable to cross either above or within the Highlands and subsequent exploratory work throws light on different possible locations in these regions. Fourteen different lines were tested by wash borings. Later some of these were tested by diamond drill. As data accumulated it was possible to eliminate many of the trial lines and the more detailed and critical studies became confined to a few important possible crossings.

In making a comparison of them as to geological environment it is evident that they fall into two distinct groups[1] [*see* fig. 15]. One, that may be designated the "New Hamburg" group is represented by the "Peggs point," "New Hamburg," and "Danskammer" lines and is characterized by a series of much folded, faulted and crushed sedimentary rocks, chiefly slates, limestones and quartzites. The other, that may be called the Highlands group, is represented by the "Storm King," "Little Stony point," and the "Arden point" lines and is characterized by crystalline metamorphic and igneous rock of a much older series.

A judgment as to the most desirable crossing involves the selection of one of these groups chiefly upon general geologic features, and finally a selection of a particular line upon minor differences of materials or structure.

In the first place it seems necessary to consider, for each group,

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[1] There have been other suggestions for crossing the Hudson river, farther upstream and farther down than these — one being at New York city — but none have had sufficient claim to attention to encourage much detailed work or so careful consideration as those here discussed.

A shift of position of the Hudson river crossing involved a corresponding shift of a large section of the northern aqueduct line. The first choice of location occasioned a shift southward of all that portion between Ashokan reservoir and the Hudson.

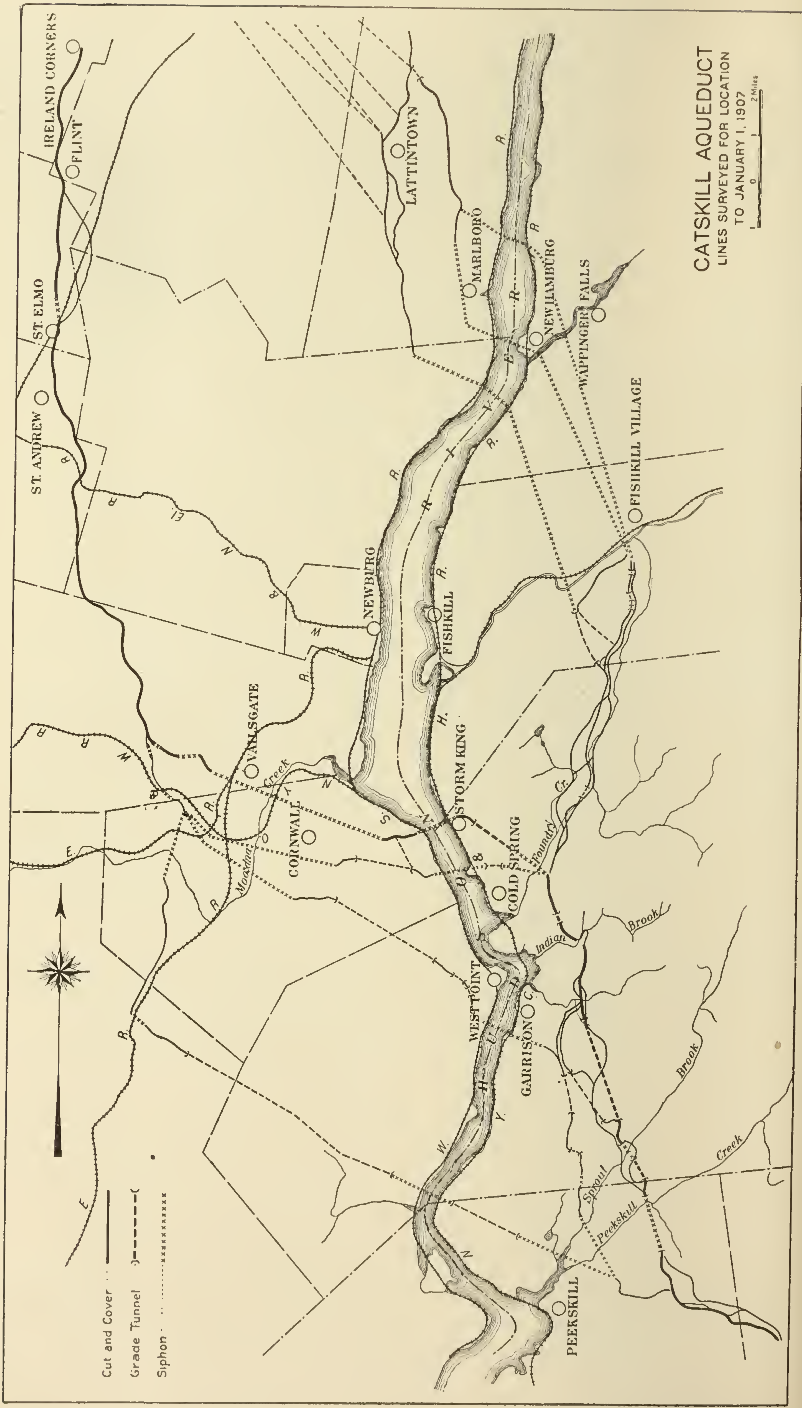

Fig. 15 Outline map showing alternative lines studied as possible crossings of th

the whole length of pressure tunnels whose position would be modified by a shifting of river crossing. This is because the aqueduct will approach the Hudson with nearly 400 feet head — i. e. 400 feet above river level or with an equivalent pressure. For this reason it is considered necessary to plan a rock pressure tunnel beneath the river which can deliver the water at nearly the same elevation again on the east side.

Thus any one of the "New Hamburg group" involves a continuous pressure tunnel reaching from the margin of Marlboro mountain to Fishkill range, a distance of approximately seven miles, while any of the "Highlands group" permits the substitution of two more or less separate siphon tunnels (Moodna creek and Hudson river) of considerably less combined total length.

A reliable conclusion as to the choice of crossing is probably best reached through a comprehensive understanding of the geologic development of the region together with a consideration of specific local conditions. With this end in view a condensed outline of geologic history, so far as it bears upon the questions at issue, is inserted. But for a more comprehensive discussion of these matters the reader is referred to the explanatory chapter of part 1.

Geology

This particular locality, including as it does the Highlands of the Hudson and the district lying along its northern border, is one of the most complicated stratigraphically and structurally to be found in the entire region. The strata represented include more than half the total geologic scale reaching from the oldest sediments following the Archean up to and including a part of the Devonic series [*see* pt 1]. The rock types include granites, diorites, gneisses, schists, marbles, serpentines, slates, quartzites, sandstones, limestones, shales, and, less extensively, other varieties. And the region bears the evidence of no less than three periods of mountain-making disturbances, each in its turn adding to the succession of foldings, faultings and unconformities.

The oldest formation is a crystalline gneiss — a characteristic rock of the Highlands. It represents an ancient sediment that has been completely recrystallized during some of the earlier mountain-making period. It is older than the Cambric. Interbedded with it to a limited extent are quartzite beds, ancient limestones (now usually serpentinous in character) and schistose beds; and in it are many igneous injections, mostly granites of various types. All

these igneous injections are therefore younger than the gneiss and are very large and abundant in certain cases. The granite of Storm King, Crows Nest and Breakneck ridge belongs to this type.

Following the sedimentary cycle represented by the above series, and perhaps others not now preserved, the region was folded into a mountain range, the series was extensively metamorphosed and passed through a long period of erosion during which it was again reduced to sea level position and began to accumulate a new series of sediments.

The lowest beds occurring upon this foundation are sandstones, now changed into quartzite. In places they are conglomeritic, and may now be seen projecting into the valleys along the Highland border. This formation is of Cambric age, and is from 200 to 600 feet thick in favored places. It forms an almost continuous belt along the north side of the Highlands except where cut out by faulting, and extends with similar breaks beneath the later sediments northward. This quartzite is known as the "Poughquag."

Upon the quartzite of this series there was developed a succession of limestone beds at least 900 to 1000 feet in thickness. This formation is known as the "Wappinger" and includes some beds that are of Cambric but for the most part of Ordovicic age.

The final member of this series is a shale and shaly sandstone in places changed to slate. It is quite variable in actual character and has a great thickness, never yet successfully estimated, but probably several thousand feet. This is the so called "Hudson River slate" series. In this region they are of Ordovicic age.

This is the succession which the proposed Hudson river lines has to penetrate in a pressure tunnel. Later Siluric and Devonic strata lie in the immediate vicinity of this alternative line, but add no complication to the problem as it now stands. Therefore no other formations need be considered except the glacial drift. This covers almost every rock surface and is deeply accumulated in some places, notably in the narrow gorges and valleys, obscuring the finer original topographic lines.

A summary of the history of the formations chiefly involved in this problem with a suggestion of later erosion activities may be tabulated as follows:

Cenozoic	Glaciation Reelevation Erosion (interrupted) Elevation (rejuvenation)

Mesozoic	Erosion to peneplain ....Unconformity A long interval including two mountain-making epochs and at least one period of general sedimentation
Paleozoic	Ordovicic: Hudson River slates; Wappinger limestone Cambric: Poughquag quartzite ....Unconformity A long interval including mountain folding, igneous injection, erosion, and perhaps other sedimentations
Proterozoic	The metamorphosed schists, limestones, quartzites etc., together with accompanying intruded igneous masses — forming the basal gneisses of the Highlands

The evidence of such succession and history gathered from the scattered outcrops of rock in the immediate area, is nowhere better shown than in the field covered by this investigation.

Structure

When such outcrops as are known are plotted and organized, several important facts become clear.

1 The folds run with remarkable persistence northeast and southwest.

2 The succession in many places is not normal. Often a whole formation or even two of them are missing and formations that should be separated are brought side by side. Faulting therefore is prevalent and the occurrences show that these large fault lines usually run northeast and southwest.

3 A consideration of the dips of the strata shows that most of the folds are overturned as if pushed by some general movement from the southeast.

4 This same movement causes the faulting to be largely of the overthrust type, and in some cases the lateral displacement attained in this way may possibly be several thousand feet.

5 Isolated "islands" of the older rock formation appear out in the later sedimentary area. They all seem to belong to prolongation of the ranges of the Highlands and their abundance undoubt-

edly complicates the underground structure throughout a considerable belt.

6 The Highlands area terminates in a serrate margin which, in the latest thrust movements from the southeast, must have created very unequal distribution of stresses within the slate-limestone region to the north causing additional cross folding and faulting. For the most part these can be traced only a short distance before losing their identity.

In a mountain folding movement, the uppermost rocks are most broken and displaced or crushed while those of greater depth may be bent or uniformly folded or even recrystallized. It would appear that this latter was the condition of the Highlands rock series during its earlier history. And even in the latest movements its lines appear to be less radically disturbed than the slates and limestones to the north. Most of the disturbances that invite serious consideration belong to the latest period of these mountain-making upheavals.

Comparison of routes

1 **New Hamburg group.** This group of crossings is in the later sedimentary series. Hudson River slates and Wappinger limestone are the chief formations. But within the southern third of the tunnel, at least, the underlying Cambric quartzite and the older Highland gneiss would be cut — the quartzite possibly three times. The succession therefore will be of considerable complexity as a whole.

All of the formations involved are thrown into very steep dips at most places and are consequently liable to rapid and unexpected changes — some of which probably do not show at the surface.

There are several fault lines belonging to the major northeast and southwest series to be crossed by such a tunnel — one of them in each case being met at considerable depth and beneath or adjacent to the river. These faults besides being the weakest zones of rock as a rule, are in addition the most unstable in any possible future earth movements. Although there is no evidence of recent displacement along these lines, still such a thing is always possible and recent serious effects of this kind on the Pacific coast suggest caution. It is manifestly advisable, if possible, from every standpoint to avoid crossing several of them.

In the field there are numerous springs of very large flow along many of the limestone borders. The concentration of them to these situations in addition to the occurrence of an occasional sink-

hole, leads to the conclusion that they are more intimately dependent upon the limestone structure for their existence than upon the glacial drift or any superficial factor. Their abundant flow, sometimes on high ground, indicates rather extensive structural connections and this is believed to be the limestone bed itself and that such flows would be encountered also in depth. The occurrence of sinkholes suggest also possible solution channels and cavities and distant outlets. The types of rock to be encountered on the lines represented by this group are easily workable. Among them all the Hudson River slates is probably the most satisfactory from any standpoint. It is generally easy to penetrate and has a capacity for healing its own fractures. For this reason it can be considered good ground, tight and safe. But a considerable distance of the tunnel can not be kept in slate — perhaps even more of it than can be proven from surface observations. The other formations are considerably less satisfactory. The limestones are in places shattered and are liable to abundant flow of water. The quartzite is extremely hard, as difficult to penetrate as granite, and where crossed by the faults is probably not healed at all, while the gneiss is doubtless of similar character to that of the Highlands crossings to be discussed later.

Only minor modifications result from a choice of the individual crossing, whether " Peggs point," " New Hamburg," or " Danskammer." In one of them, New Hamburg, it would appear possible to cross the actual river section wholly in slates. This seems to be the reasonable conclusion from the diamond drill boring at Cedar Cliff. But even that line necessitates crossing at least two fault contact lines immediately at the east bank and beneath Wappinger creek at depths not immensely less than that below the river itself and both wholly within the range of influence of the river waters. It would appear therefore that the situation is not materially altered in the present discussion, no matter which particular crossing of this group is considered.

2 **The Highlands group** [*see* cross section]. In this group of crossings there are two separate features to consider. (*a*) the Moodna creek valley which these lines all cross, and (*b*) the Hudson river itself. Their characteristics are as follows:

a Moodna creek [*see* separate Moodna creek discussion]. So far as known Moodna creek can be crossed almost wholly in slate. It is possible that the underlying limestone may come near enough to the rock floor of the valley to be penetrated but there is little

direct evidence of it. The ancient valley is deep and probably marks a line of displacements which can not be avoided, no matter what route is chosen. The fault contact at the border of the Highlands is not expected to prove troublesome as it seems very tight at the exposures seen. The buried granite ridge (a continuation of Snake hill) which underlies the western end is now known to come within the limits of the tunnel and adds one more complication.

Except for the fact that the ancient Moodna valley is deep and filled with heavy drift that is unusually difficult to prospect, there would seem to be no source of special trouble. It has no lines of weakness that are not also present in the more northerly districts and the tunnel has chances of crossing them under more advantageous conditions without so much complication with the limestone series as characterizes the New Hamburg group.

b Hudson river. Among the Highlands group of crossings there is considerable difference of structure dependent upon the exact location of the crossing. The conditions that prevail may be summarized as follows:

(1) **Storm King location.** This is wholly in massive and gneissoid granite. The rock is the most massive and substantial body of uniform type found in the Highlands. The course of the river indicates some weakness in that direction. This weakness may be some minor crushed zone or even the jointing alone that prevails throughout the exposed cliffs. But there is no direct evidence of faulting, cutting the line and such crushing as may be encountered is believed to have originated at such depth and under such conditions as to cause no large disturbance. The freedom of this formation from all bedding structures and natural courses of underground water circulation on a large scale is an additional factor. There is absolutely no other place, within the region, where the Hudson river can be crossed from grade to grade in good ground of a single type with so great probability of avoiding all large lines of displacement.

(2) **Little Stony point location.** The conditions that prevail at this point are similar to those that characterize the Storm King line. The only known difference is in the considerably more shattered condition of the granite, especially on the west shore at Crows Nest. It is estimated that this crossing is less favorable by reason of just this poorer condition of the rock and the somewhat greater yielding to regional disturbances that it seems to indicate.

(3) **Arden point or West Point location.** On this line the river would be crossed in the gneiss series proper instead of in granite.

The Storm King — Breakneck mountain gateway to the Highlands as seen looking north from West Point. Two of the proposed crossings lie in this gap — the Storm King line reaching to Breakneck, the rugged mountain on the east side, and the Little Stony Point line which crosses from Crows Nest on the west to Little Stony Point, the small low point on the east side. (Photograph by Board of Water Supply)

It is largely an ancient stratified series much metamorphosed containing belts of interbedded limestones, quartzites, and schists, in addition to the more substantial feldspathic gneiss. The eastern bank of the river bears also abundant evidence of extensive crushing and shearing and is believed to indicate a displacement in this zone. For these reasons the West Point crossing is considered an unfavorable route compared to either of the others of the Highlands group.

Summary. In a comparison of the geologic features that are of most importance in contrasting the possible routes for the Hudson river crossing the following points are considered of most importance.

1 The New Hamburg group of crossings involves (*a*) the longest tunnel, (*b*) the more complicated structures, (*c*) the greatest number of known faults, crush zones, and related disturbances, (*d*) the more variable series of rock types to be penetrated, (*e*) the greater tendency to encounter heavy underground water circulation, (*f*) the greater probable susceptibility to disturbance from future earth movements, and (*g*) the greater number of uncertainties of rock relations.

2 In contrast the Highlands group admits of (*a*) shorter total tunnel length, (*b*) the most profound fault lines of the district are crossed either in high ground or are avoided or, because of the rocks involved, promise the least possible trouble, (*c*) the Hudson river itself can be crossed in a single formation with probability of avoiding lines of largest structural weakness confining the greatest pressures and deepest tunnel work within the most uniform and substantial rock of the whole region.

There are, of course, many unknown or only partially known features obscured beneath the covering of drift or lying beneath the river itself; but, however many there may be, it is not believed that they can materially change the general situation. The major characteristics are so well marked that any addition to those already known would in all probability increase the difficulties of the New Hamburg group of routes at least as much as and perhaps more than those of the Highlands group.

In view of the above facts and inferences the judgment has been in favor of the Highlands group of crossings as the more defensible on geologic grounds as a route for the aqueduct line. Furthermore, in accord with the preferences already noted, the Storm King location is regarded as the most likely to give satisfactory results.

Quality and condition of rock

The rock of Storm King mountain and of Breakneck ridge at the Hudson river crossing is a very hard granite with a gneissoid structure of variable prominence. The color varies from grayish to light reddish and the structure is always coarse passing into pegmatite facies that occur as stringers or irregular veinlets. The grayish facies is of slightly finer grain and more gneissoid. Those portions that have been sheared are still darker. There are many joints at the surface running at various angles and an occasional slickensided surface. The mass is cut by several dikes of more basic rock (diorite) of widths varying from a few inches to 8 feet. These dikes are somewhat more closely jointed than the granite and consequently a little more readily attacked by the weather. But where protected they are equally substantial for underground work.

The chief variation from this condition is where crushing or shearing has induced metamorphic changes. Wherever bed rock has been reached at this point and to such depths as workings have penetrated the rock is of this type.

The work includes (*a*) four inclined drill holes from the river margin — two starting from the surface and two from chambers set off from shafts at a starting depth of about 200 feet, (*b*) several vertical holes in the river itself, and (*c*) two large working shafts 20 x 20, one on either side of the river.

These give all the data[1] known as to the condition at depth. From them it is apparent that crushing and shearing have been prominent. Many splendid specimens of crush breccia are thrown on the shaft dump. But its present condition at the depth involved is sound and durable. The fractures are rehealed. There has been a recombination of constituents giving a new matrix of complex silicates among which epidote is the most characteristic, while simple decay is of little consequence. For strength and permanence the conditions could not well be improved. There is no reason to apprehend any change for the worse for the reason that the same tendencies must prevail at that depth throughout. It would appear therefore that faulting movements, or the existence of a fault zone of importance can not become a serious obstruction, because of the tendency to

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[1] Since this paragraph was written four inclined diamond drill borings have been made from chambers at depths of about 200 feet in the shafts. These have now penetrated the whole distance beneath the Hudson with very satisfactory results.

Storm King mountain and the Hudson river from Breakneck mountain showing the location of the proposed pressure tunnel by the line of drill rigs engaged in exploratory boring. (Photograph taken November 26, 1907. Board of Water Supply)

heal up the fractures and so make the rock about as substantial as before.

It is noted elsewhere that faulting is common in this region, and that in a considerable portion of its lower course the Hudson probably follows such structures. It is, however, wholly unnecessary to assume that its whole course is a fault line. Whether or not there is a longitudinal fault zone of any prominence in the river at Storm King is unknown. There are several cross faults, both above and below this point, that give much clearer surface evidence of their presence. Fault zones have proven to be objectionable ground in many places along the aqueduct line, but elsewhere the data refer chiefly to situations favoring more ready underground circulation, i. e. at higher levels. In this particular case the rock in question lies below former ground water level within the belt of cementation rather than up in the belt of decay, and there is probably no disintegrated rock from any cause.

CHAPTER IV

GEOLOGICAL FEATURES INVOLVED IN SELECTION OF SITE FOR THE ASHOKAN DAM

Topographic features of the southeastern margin of the Catskills, where the chief water supply is available, fixes the approximate location and bounds of the principal reservoir. The accompanying map, a portion of the western part of Rosendale quadrangle, shows the situation. The part of the work involving the chief geological problem was the choice of the principal dam sites on the Esopus. This is known as the Ashokan dam. This part of the Catskill system belongs to the Reservoir Department under Mr Carlton E. Davis as department engineer.

There were originally considered three sites: (1) at "Broadhead bridge," (2) at "Olive Bridge," (3) at "Cathedral gorge" or the "Tongore" site. Any one of these seemed possible from a topographic standpoint. Later developments in regard to storage capacity and engineering considerations finally reduced the practicable sites to two — the "Olive Bridge" and the "Tongore." These were then explored thoroughly as an aid to determining whether or not there were favorable or unfavorable conditions at either location. Trenches were dug, shafts were sunk, wash holes were put down, and drill borings were made. The amount of such work done was sufficient to show the actual conditions both of the drift and bed rock and incidentally to throw some light on minor matters in geologic history.

This discussion is essentially a summary of these data and a comparison of the geologic conditions indicated by the explorations[1] of these two sites and a statement of some of the geologic characteristics of the area.

1 General geologic conditions as shown by the explorations

Bed rock is dark colored Devonic sandstone and shale, the Sherburne formation, lying almost horizontal, strongly jointed, plainly bedded, and of good quality for the foundation of the dam.

At both locations the present Esopus flows in a postglacial gorge

[1] In this work of exploration a very efficient staff of engineers was engaged. Among those having very much to do with the features here discussed are Thaddeus Merriman, division engineer, J. S. Langthorn, division engineer and Sidney Clapp, assistant engineer.

and there is a somewhat deeper buried channel a short distance to the north side. In each case this old channel bed rock is probably less fresh and substantial, due to former weathering, than the present exposed surfaces.

In each case glacial deposits reach a thickness of more than 200 feet within the narrow valley or gorge, especially along the north valley wall within the limits of the proposed dam.

Special geological conditions. The factors in which there is most variation and which are of most significance in a comparative study are those belonging to the glacial drift deposits. In order to properly estimate the influence of some of these features it will be necessary to briefly consider the types of material represented at different places and the conditions under which they were formed.

Types of material. *Till.* Heavy bouldery till, mixed clay, sand, gravel, and boulders, is the most abundant type of material. It forms especially the chief surface material throughout the region, and is the surface type at both sites. It becomes at places quite sandy, but is almost everywhere good, impervious material because of its mixed character.

Laminated till. At a few places, notably in the Beaver kill near its mouth, and in a trench above Olive Bridge, and in the "big dugway" above West Shokan, strong lamination appears in heavy stony till as if laid down rapidly in comparatively quiet water such as the margin of a lake. This material is especially impervious.

Gravel hillocks. A few small hillocks with morainic contour, indicating a dumping ground for some glacier on a small scale, occupy the flat immediately west of Browns Station. They were, at a very late stage, piled into the course of a former glacial stream whose delta deposits occupy the sandy bench above the 500 foot contour just north of Olive Bridge.

Assorted gravel and sand. This material is abundantly developed just north of Olive Bridge. It seems to have formed a delta deposit at the mouth of a glacial stream that emptied into the main valley at this point. The running water washed almost all of the clay and extremely fine material farther out, where they settled in the bottom of a small glacial lake that was at that time held in this upper portion of the Esopus valley. The dam that held in this body of water which reached above the 520 foot line stood near the proposed "Olive Bridge" dam site. The materials forming the dam were in part the glacial till that is now found on that site and

Cut-off trench in the Sherburne sandstones and shales at Olive Bridge dam (Ashokan). (Photograph by Board of Water Supply)

in part the ice itself, which came in from the northeast, helping to complete the barrier. Into this lake the streams from the melting ice margins deposited their load of silt. This is well shown in the trenches cut across the terrace ¾ of a mile above Olive Bridge.

A similar occurrence is seen at the cemetery near West Shokan.

Laminated sand and clay. In all cases where silts were carried into the lake basin the finest materials were carried in suspension to greater distances from the margins, and slowly settled out in the form of alternate laminae of clay and fine sand. Each sandy layer represents a fresh supply of material and rapid precipitation of the comparatively heavy grains; while each clay layer represents a period of greater quiet or decreased supply during which the finest particles settled to the bottom. A predominance of fine sand indicates either abnormal supply or proximity to the supply margin, while a predominance of clay represents either uniform and moderate supply or greater distance from the supply margin.

These deposits are nearly impervious to water moving vertically, but much more pervious laterally and especially so in the most sandy portions forming the marginal facies.

This type of deposit is to be seen at the surface at about the 700 foot contour 2 miles north of Shokan, above the "big dugway," also in the trenches cut into the terrace at about the 500 foot contours ¾ of a mile north of Olive Bridge, and it is probable that this same type underlies the northern half of the "Tongore" site. The material marked "fine sand" at and below the 400 foot line on the accompanying "geologic section" *G-H* is judged to be of this type.

Pebbly clays. These are developed to only limited extent and indicate probably floating ice in addition to the other methods of distribution.

Gravel streaks and assorted pebble beds. Wherever water flowed with considerable current across the material either before or after deposition the finer particles were removed and only gravel and pebbles, too heavy to transport, were left behind. Some of these gravel beds were developed in the intervals of successive advances and retreat of the ice when for a time the lower valleys were unoccupied. In many places the succeeding advance of the ice would plow all these surface materials up again and mix them into the usual till; but occasionally the oncoming glacier simply covered these deposits with its own till mantle, and they are preserved as records of these minor interglacial stages. Such behavior would be

more likely to occur in the deeper channels. To this class of deposit belong some of the gravel beds of the "Tongore" site, notably that shown in one of the deep shafts. It is probable that the zones where the wash rig experienced a "loss of water" are most of them of this type.

2 Summary of geologic history

In preglacial time the Esopus valley was occupied by a stream of similar capacity to the present Esopus creek. Its channel lay to the north side of the narrow valley, having adjusted itself in conformity to the slight dips of the Hamilton sandstones and its principal joints. At the points under investigation this original channel is buried under several kinds of glacial deposits whose source of accumulation was chiefly from the north and northeast, blocking the stream channel and forcing the stream to the opposite (south) side. The direction of movement was favorable to the damming of the Esopus creek valley and the deposits indicate that this occurred at several different times and at different elevations and that corresponding lake conditions occasionally prevailed. It is equally clear that there were intervals of retreat of the ice with attendant stream action and the development of gravel beds, followed by another ice advance, either obliterating the surface features or covering the previous deposits with another till layer. With each successive withdrawal the local streams found themselves more or less completely out of place, and consequently their characteristic deposits formed in these intervals may be found in unlooked for places wholly inconsistent with present surface contour.

At the final withdrawal of the ice, Esopus creek found itself entrenched along the southern margin of the valley and has cut a postglacial rock gorge instead of removing the compact till from the original channel. But wherever only modified drift, either sand or clay, was the valley filling it scooped out great bends so that a large proportion of this type has been removed from the valley, and only the margins remain as terraces or covered beneath other protecting deposits.

3 Application to the choice of dam site

a **"Olive Bridge" site.** The trenches and shafts together with surface exposures indicate that the glacial drift at the Olive

Plate 19

View across the Esopus valley to "Millwheel Gap." In a portion of this glacial lake basin modified sands and clays were deposited while an ice barrier closed the outlet of the valley. The "Gap," the sharp notch in the lower slope of the mountain, is interpreted by Darton as the outlet or overflow for the surplus waters during that stage. (Photograph by Mr J. E. Hyde of Columbia University)

Bridge site, at one stage in the glacial history, served as a natural dam and that water was successfully held above it to an elevation of 530 feet and perhaps more.

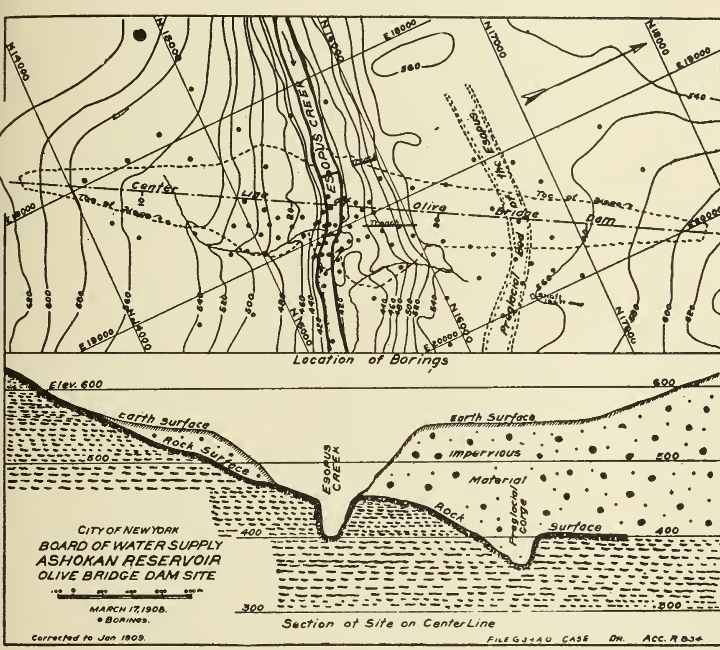


Fig 16 Location of the Ashokan dam at Olive Bridge site and a geologic cross section. The small dots in the plan indicate exploratory borings. The section shows the rock profile indicating a preglacial channel of the Esopus. The present Esopus flows in a new postglacial channel at a higher elevation.

The lowest materials in contact with bed rock are heavy stony till, laminated till and stony laminated clays — all good impervious material wherever exposed and tight upon bed rock. Sands and laminated clays are extensively developed immediately northward of the site and streaks of these deposits interlock to a limited extent with the till materials of the site itself, but they do not extend far and die out in wedges among the heavy deposits that characterize the southern slopes of the hill forming the northern terminus of the dam. These pervious streaks do not extend at any point continuously through this hill and consequently as a whole the present barrier as it stands is practically impervious. The poorer materials (assorted gravels and sands) characterize the upstream side, and the better, more impervious materials (till and laminated boulder clays) characterize the downstream side of the proposed Olive

Bridge site. It is therefore advisable to locate any such structu as a dam at a point as far down stream on this site as other eng neering factors permit.

b "**Tongore**" **site.** At Tongore, bed rock is at least a hun dred feet deeper than at Olive Bridge. In the deeper parts, belo the 400 foot line the deposits as indicated by the wash borings [*se* sections] are interpreted as a fairly continuous succession of til stratified sands and gravels, and laminated sands and clays belong ing to two or three different stages of accumulation. Upon thi the heavy upper till was laid down. It is believed that the record fully support this view and that the stratified or laminated material were accumulated at a time when a temporary dam existed at som point still farther down the Esopus valley. It is apparent further more that the most porous zone is at the junction of the uppe till and the lower stratified deposits and in part is represented b the assorted pebbles of stream wash — in general not far from th 400 foot line. These middle zone deposits are believed to exten continuously through the drift ridge that forms the northern hal of this site. As before noted, though rather impervious verticall

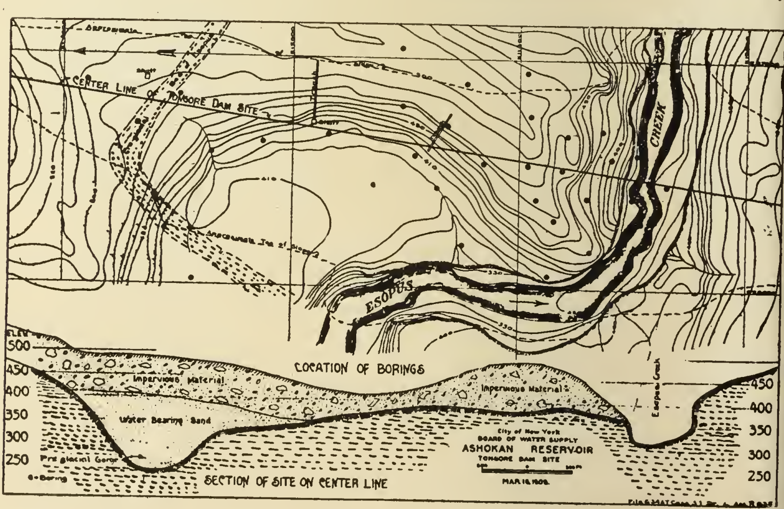


Fig. 17 Plan and geologic section at the Tongore site. The dots on the map indicate exploratory borings and the course of the buried channel of the preglacial Esopus creek is shown making a right angle bend to the north. The section shows the buried channel, the new postglacial channel and the great accumulation of porous modified drift which is regarded as one important objection to this site for the dam.

some of these deposits allow ready lateral movement of water. This is held to account for the rather persistent occurrence of springs or seepage along the creek bank at about this level both above and

Plate 20

Cathedral gorge, a postglacial entrenchment of Esopus creek at the Tongore site. The preglacial gorge lies at the north side of the valley buried beneath 250 feet of drift. (Photograph by Board of Water Supply)

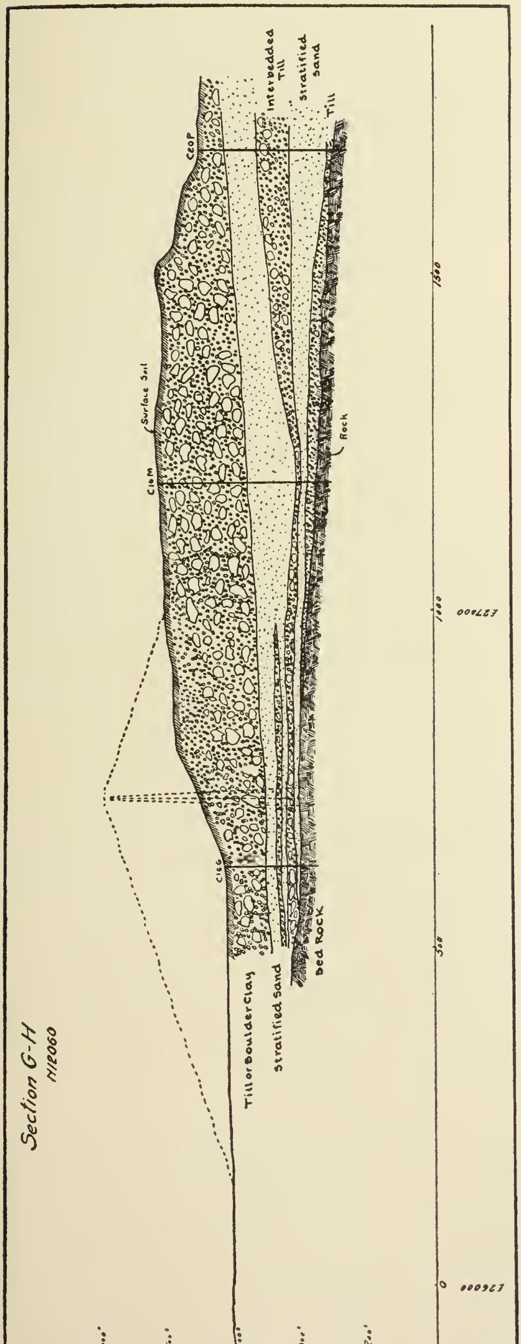


Fig. 18 Detail of drift character at the Tongore site showing extensive and continuous stratified sands characterizing this location, which, because of their perviousness, represent poorer geologic conditions than were found at the rival Olive Bridge site.

below the site. The great thickness of these laminated beds, in places a hundred feet or more, together with the abundance of sand in them, and the caving tendencies exhibited by them in one of the large shafts, indicates poor conditions for such a piece of work.

The behavior of one of the test shafts throws some light on conditions within the drift deposits. At this place after sinking into the underlying gravel beds there was " no water " at first, but after going a few feet deeper there was an abundant flow, that did not rise much in the shaft. This case seems to support the following interpretation.

The gravels encountered do not form an isolated pocket or lens, else it would have carried water full from the first. It must be a fairly continuous porous zone with large feeding connections else it would run dry, and it must have an easy discharge else it would have risen above the level of the first gravels. Therefore it must be a rather well marked subterranean water passage or porous zone of considerable extent. Such conditions would make an impervious core wall to bed rock at this site a necessity and its construction a matter of considerable difficulty. At this site also because of the small cross section of the ridge, there is little chance for the interlocking of layers or the blocking of the porous ones by a till barrier to check the lateral seepage, and there is no chance to move farther down stream to secure such conditions.

4 Summary

Because of the (*a*) higher bed rock throughout, and (*b*) the more uniform and impervious quality of drift deposits, and (*c*) the more massive cross section of drift barrier for foundation, and (*d*) the perfectly tight contacts of till and bed rock, and (*e*) the limitation of the more porous materials to higher levels and (*f*) the glacial history connected with the development of all these parts, "*Olive Bridge*" is the preferable location for the proposed Ashokan dam on Esopus creek.

CHAPTER V

CHARACTER AND QUALITY OF THE BLUESTONE FOR STRUCTURAL PURPOSES

Probably no stone marketed in New York State is more extensively known than the "bluestone" of the Catskill region. But it is noted particularly for a special purpose, i. e. as flagstone, because of its capacity to part or cleave into thin slabs. These slabs are proven by experience to have remarkable weather resistance and durability.

Little attention has been given to the question of dimension stone — whether or not such blocks of as high quality as the flags could be obtained and where such quarries could be opened.

There are several reasons for this situation. In the first place (1) the stone is of a dark color and has a dull appearance so that it is not fancied for the usual expensive structures where large sizes are used, also (2) the quarries are small, shallow, and are worked on a small scale by single individuals or groups of neighbors with few quarrying tools and no transportation facilities for large material, and in addition (3) considering the work and equipment necessary and the demand the flag industry was more profitable.

Because of the large demands of the Ashokan dam where nearly a million cubic yards of heavy masonry construction are to be used an entirely new situation has developed. It is especially desirable that a rock capable of furnishing heavy dimension blocks should be discovered. The usual slab or flag type is unsuited to a considerable part of this work. A study of the adjacent region therefore has been made and explorations along certain promising lines have been conducted to sufficient completeness to prove that a suitable stone can be furnished in large quantity. The characteristics of structure and occurrence as shown by this special study are given, together with some of the later exploratory data.

Physiographic features[1]

All of the rock formations are sedimentary, chiefly sandstones and shales. They lie in alternating beds of variable thickness and are almost horizontal. The total thickness is many hundred feet so

[1] The principal argument of this discussion has been used in a previous article by the writer under the title "Quality of Bluestone in the vicinity of the Ashokan Dam" in the School of Mines Quarterly, v. 29, no. 2.

that neither the bottom nor the top beds of the series are to be see in this locality.

The region is one of considerable relief representing preglaci erosion. The glacial drift mantle has modified it chiefly by obscur ing some of the smaller irregularities of rock contour, and espe cially by partially filling many of the stream gorges. Postglacia erosion has not completely reexcavated the old channels. But th contour of the uplands reflects the character of the bed rock wit considerable success. The tendency of the more massive and coars grained varieties of rock to resist weathering and erosion more suc cessfully than the finer grained and more argillaceous or shal facies is a general characteristic. Since these varieties form suc cessive or alternating beds throughout the whole area, the result i an almost universal cliff-and-slope surface form. This bed roc topography is somewhat obscured but not wholly obliterated b glacial erosion and deposition. Therefore it may be used with confidence in locating or tracing the more durable beds since they almost invariably appear as a shelf or terrace with a steep margin toward the lower side and a gentle slope on the rising side.

Structural features

The rock types include bluish gray or greenish gray sandstones with almost horizontal bedding, and sometimes exhibiting cross-bedding structure, and compact very dark argillaceous shales. These two are of about equal prominence, but only the sandstone is of importance in the present discussion. Its minute structure will be given in greater detail in the petrographic discussion.

Jointing is common and persists in two sets nearly at right angles to each other — one striking northeastward and the other toward the northwest. In some of the best exposures, these joints are clear-cut and run 10 to 18 feet apart, dipping almost vertically. In the more massive beds there is very little small jointing, so that the character is especially favorable to large dimension work.

But still more prominent structures are the partings which follow the bedding planes. These give the rock a decided tendency to cleave naturally into slabs, the uppermost exposed portion of almost every outcrop exhibiting this slab structure in more or less perfection. So general is this structure at all horizons in the sandstones of the series that there can be no doubt of its connection with some original sedimentation character. Besides it is a potential factor in nearly all the beds even when not very apparent. The

The Sherburne flags, showing their horizontal bedding and two very regular and prominent sets of joints. (Photograph by Board of Water Supply)

exposed places exhibit the character so prominently only because of the weathering effect, which develops the natural tendency. This general conclusion is borne out by the well known practice of quarrymen of the district of splitting the larger blocks into slabs of the required thickness by wedges driven along certain streaks that are known as "reeds." A reeding quarry is one that has this capacity well developed, and it is this character in part that has made the "bluestone" or "flagstone" of New York an important factor in the production of the United States for a great many years.

For large size dimension stone where great stress is involved it is evident that this structure would not be desirable. These definite planes of weakness reduce the general efficiency. A little observation however shows that there are some outcrops and an occasional quarry where the more massive blocks do not split well. From the necessities of the industry these have been avoided or but meagerly developed. In some cases of this kind the sedimentation is of the cross-bedded type with somewhat interlocked laminae. If the grain is coarse such varieties resist splitting with great success. The thickness of such beds varies from a few feet to 25 feet or even more without prominent interbedding of shale layers.

Stratigraphy. These are the sandstones, flags and shales known as the Hamilton, Sherburne and Oneonta formations belonging to the Devonic period. The strata of the immediate vicinity of this examination belong to the Sherburne subdivision, but no attempt to differentiate the formations was made. Structurally and petrographically the different formations are not distinguishable in this area. On the market the stone from either is known generally as "Hamilton flag" or "bluestone."

Economic features

There are hundreds of quarries in this general region. Nearly all are small, and are worked on a small scale without machinery. The product is almost wholly thin slabs of the flagstone type. This is supplemented by a small amount of somewhat more massive character, dressed for window sills; and a very limited output is of dimension stone of larger size. The general lack of suitable mechanical devices and transportation facilities are the chief reasons for the limited output of the last named grades.

Petrography

The basis of this discussion is a microscopic examination of several thin sections made of the different types of rock from the

quarries whose field geologic features give promise of encouragir results. The most characteristic variations are illustrated in tl accompanying photomicrographs, plates 22, 23.

Texture. The rock is granular, the individual grains varyin from minute particles in the finer shale layers to three or fou tenths of a millimeter in diameter in the coarser sandstone [pl. 2 lower figure]. The grains are seldom rounded. Jagged or fraye or elongate forms are the rule [pl. 23, upper figure]. There is n marked porosity. When the rock was first deposited as a sedimer it probably had the usual large interstitial spaces of such rock typ but in this case some subsequent modification — an incipient meta morphism — has largely obliterated the voids by the introduction o development of mineral matter of secondary origin.

In general it is quite apparent that the average grain was orig inally more rounded than its present representative.

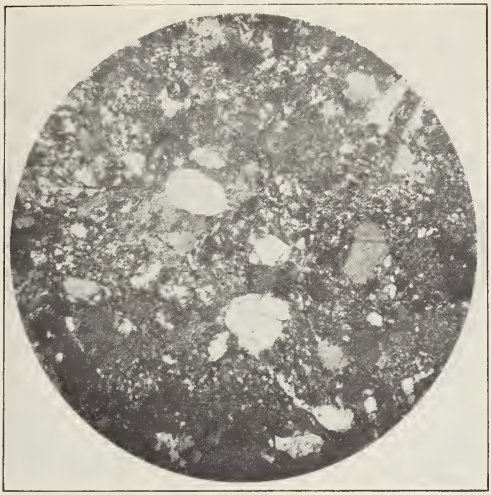
Mineralogy. The original minerals in order of abundanc were the feldspars, quartz, and probably hornblende, biotite, and ir much smaller amounts others of little apparent consequence in th present discussion.

All of these have been more or less affected by subsequen changes. Quartz has suffered least of all, the chief modificatior being a greater angularity of form and an occasional interlocking tendency caused by secondary growth [pl. 22, lower figure].

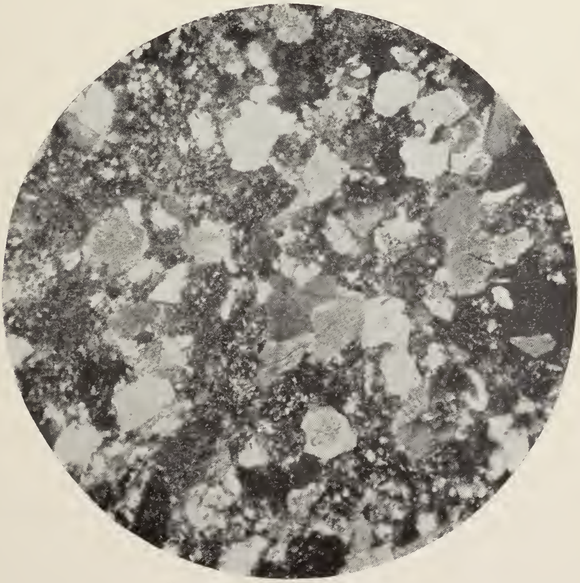
Both orthoclase and plagioclase feldspars occur. The orthoclase grains, which originally made up more than half of the bulk of the coarser types of rock, have been in places profoundly altered [pl. 22, upper figure]. In many cases the identification of this mineral depends upon its association and the abundant remnants of characteristic structure and its normal secondary products. In the least affected grains satisfactory identification is not difficult. Even in the most modified representatives there is some preservation of structure indicating size of grain and proving the essentially granular character of the rock. The plagioclase, although not abundant, is more readily detected than the orthoclase because it has been much less affected by the secondary changes.

All original ferromagnesian constituents are wholly altered. There were some such constituents in the rock, as is plainly shown by the secondary products. Hornblende and biotite were probably both present.

The secondary products, derived from the original feldspars and ferromagnesian constituents, include sericite, chlorite, calcite and



Photomicrograph of bluestone, x 25 diameters. The clearer grains are quartz and indicate the approximate size of other original constituents. In this case the alteration of the feldspars and ferromagnesian originals is so complete that their products form an indeterminable complex aggregate of closely interlocked granules, flakes, and fibers of extremely fine texture.



Photomicrograph of first grade medium grain bluestone, x 25 diameters. Taken to show angular and interlocking grains indicating secondary growth and a complete lack of reeding structure. The clear grains are quartz; the rest of the field is made up chiefly of secondary derivatives from the original feldspars and ferromagnesian minerals.

quartz as the most important and abundant. Others probably occur that are less readily differentiated, and among them is kaolin. Occasionally a small amount of massive or granular pyrite occurs. There are traces of organic remains, especially plant stems, and the pyrite is most plentiful in association with those beds.

It seems to be the secondary products largely that give the characteristic bluish or greenish color to this stone. Practically all of the iron freed by secondary changes from the ferromagnesian constituents has entered into new silicate compounds, especially with the chlorite, which are minutely distributed throughout the whole mass, giving it all a tinge of the characteristic color of these well known products. The same amount of iron in the oxid form would no doubt give as highly colored stone as any of the reds or browns of other familiar types of sandstone. But the tendency to form the sericite-chlorite-quartz aggregate in the rock has also an important bearing on its durability and strength. This is further discussed in a separate paragraph.

Classification. It is clear that this type of bluestone is a sedimentary rock of medium grain, a sand rock or " renyte." Since the silicates are so predominant in the original composition it may be further identified as a sandstone or a " silicarenyte." But in view of the predominance of the feldspars it should be further designated as an arkose sandstone. And considering the extent to which it has been modified by the development of interstitial silicious products and the effect that this has had in perfecting the bond between the grains, the rock may be classified as an indurated arkose sandstone.

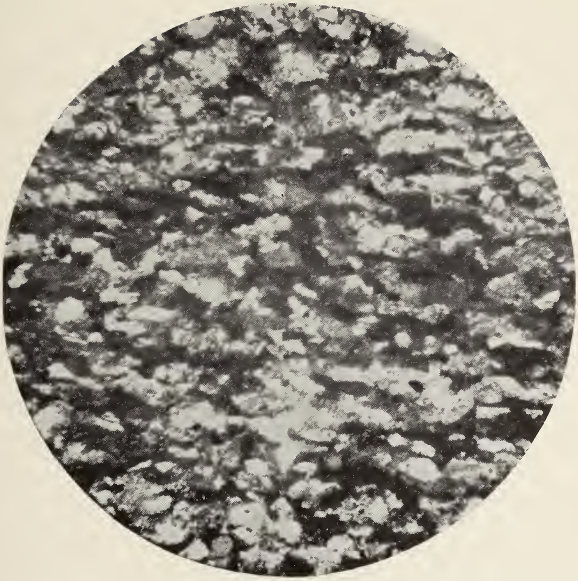
Special structure. A study of the cause of reeding, or the tendency to split into slabs, led to the preparation of thin sections of this structure [pl. 23, upper figure]. It is apparent from them that the reed is strictly a rock structure and that the perfection of the capacity to split along these planes depends wholly upon the abundance and arrangement and size of the elongate and semifibrous grains and the presence of a more than usual amount of original fine or flaky material. Almost universally the reed streaks are darker in color and finer in grain than the average of the rest of the rock.

In part therefore it is an original character due to the assorting action of water during deposition, finer streaks alternating with coarser ones in accord with ordinary sedimentation processes. But, in addition to that, the subsequent changes that have affected the whole rock have occasionally accentuated the structure by a ten-

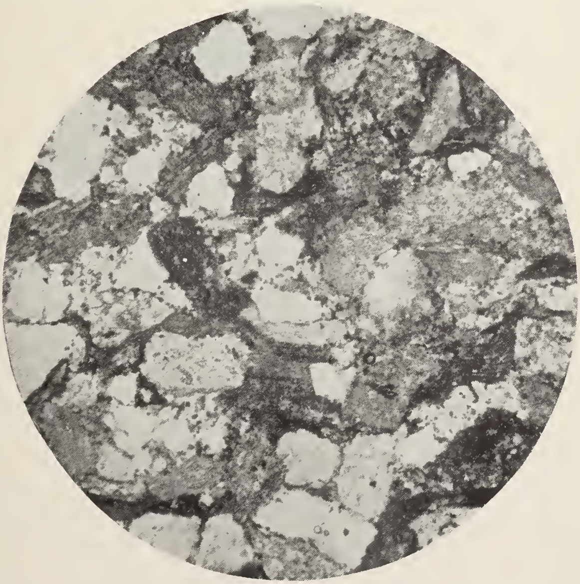
dency of the whole rock to develop elongate or fibrous aggregate. It is probable therefore that the parting capacity is in places considerably increased by the very process that has produced just the reverse results in the more heterogeneous portions of the beds.

Under a sufficient stress the rock will part most easily along the planes where this foliate or fibrous character is most persistent. Even in these cases, however, it may not indicate that the rock is essentially weak. It simply locates the most vulnerable point in the stone. In many quarries these streaks are so abundant that only thin slabs can be obtained — the disturbances of ordinary quarrying being sufficient to cause parting. The deeper portions of quarries are, however, much less subject to such behavior. In all cases the greater slab development of the exposed portion of the ledge is an ordinary weathering effect, by which the same results are obtained slowly and naturally and more perfectly than can be secured artificially on the fresh material of the same beds. The expansions and contractions of changes of temperature, together with the rupturing effects of freezing water caught in the pores serve finally to weaken every part of the rock. In this process the prominent reed lines give way so much in advance of the rest of the rock that they develop into true rifts and separate slabs appear. It must be appreciated that these ledges have been exposed an immensely long time compared with the probable requirements of any engineering structure, and that this weathering tendency does not mean a speedy disintegration of the freshly quarried blocks. Still it is advisable to avoid as many sources of weakness as possible and one of the ways is to select ledges where the stone does not have a reeding tendency, or in which the reed lines are interlocked, or wavy, or interrupted. These requirements are most fully met in the coarser beds and especially those exhibiting some cross-bedding. Two local quarries meet these demands to a marked degree.

Strength. The better qualities of bluestone have great strength. Even the reed lines are in many instances stronger and more durable than the regular quality of some other sandstones that are usually considered suitable building material. The secret of this exceptional strength lies in the modifications of texture that have resulted from the alteration and reconstruction of the mineral constituents. The breaking up of the orthoclase feldspar, and the accompanying changes in the ferromagnesian minerals, have furnished considerable secondary quartz, which has in part attached to the original quartz grains making them more angular and de-



Photomicrograph showing structure of the reeding quality of "bluestone." Magnification 30 diameters. Taken to show tendency to parallelism of elongate grains.



Photomicrograph of best grade coarse-grained bluestone. Taken to show a quality in which the granular character is still well preserved. The clear grains are quartz, the others are chiefly feldspars somewhat modified. The close interlocking and the development of fibrous or frayed structure and the bending or wrapping of some constituents are secondary effects.

veloping an interlocking tendency [pl. 22, lower figure]. At the same time the fibrous sericitic and chloritic aggregates have developed to such extent as to fill most of the remaining pores, and in many cases the fibrous extensions have actually grown partly around the adjacent quartz grains [pl. 23, lower figure]. The effect has been to develop a silicious binding of unusual toughness. This combination of changes has made a rock that is now remarkably well bound or interlocked for a sedimentary type.

Durability. First-class stone of the grades indicated above would have as great durability as any stone in the market, except perhaps a true quartzite. With the exception of the almost neglectable quantities of pyrite, occasionally found, there is no constituent prominently susceptible to decay. The rock as a whole mineralogically is stable and its texture indicates unusual resistance to ordinary disintegrating agencies.

General conclusions

From the microscopic study it is clear that the variety of rock most fully meeting the demands of heavy exposed construction are the coarser beds and those freest from reed and shale.

From the field study it is apparent that ledges of suitable character occur occasionally and that at least three such are not far from the Olive Bridge site.

From additional explorations it is certain that ledges of high grade rock occur, and that the grade varies rapidly in the same bed and that suitable material can be obtained in the immediate vicinity of the Ashokan dam. No doubt rock of equally high quality may be obtained at many other localities.

CHAPTER VI

THE RONDOUT VALLEY SECTION

Because of the fact that the hydraulic grade of the Catskill aqueduct as it approaches the Rondout valley is nearly 500 feet A. T., an elevation more than 300 feet above the lowest portions of the valley and more than 200 feet above very large areas of it, a total width of more than 4 miles being too low for unsupported construction of some kind, and because of the general policy of using the pressure tunnel system so as to deliver the water at a corresponding elevation on the east side of the valley, and further because of the very complicated geological features of the district this section has been the seat of very extensive and interesting explorations.

Undoubtedly a greater number of obscure features occur here than on any other single section of the whole aqueduct line. Most of these features are readable from surface phenomena in general terms. In all cases the indications are plain enough to serve as a guide to well directed tests, but many points of critical importance can not be determined with sufficient detail and accuracy of position for such an engineering enterprise without systematic exploration.[1] The basis and results of this line of investigation which has occupied the greater part of two years are summarized and plotted in the following discussion and charts. The portion receiving special study is in the vicinity of High Falls.

General geology

Almost everywhere the surface is glacial drift. Where outcrops of bed rock occur they habitually present the unsymmetrical ridge appearance usually with a more or less sharply marked escarpment on one side and a gentle slope on the other. The strike of these

[1] These explorations belong to the Esopus division of the Northern Aqueduct Department. The earliest reconnaissance was done under the direction of James F. Sanborn, division engineer, who was subsequently assigned to geologic work over a considerable portion of the Aqueduct line. The development of exhaustive explorations and final construction on this division has been carried on under Lazarus White, division engineer, assisted by Thomas H. Hogan. The division has been recognized from the beginning as an important one and in many ways one of the most complex. Thomas C. Brown, now professor of geology in Middlebury College, was employed for a year on this division during the later exploratory work.

features is in general northeasterly and on the gentle slope is th
westerly one.

It is apparent at once that the valley bottom is a complex or
and that its history has been somewhat obscured by the glaci
deposits.

Formations. The following distinct stratigraphic units are dete
minable in this valley every one of which will be cut by the tunn
beginning at the west side with the youngest formations:

	Fe
Hamilton and Marcellus flags and shales	700
Onondaga limestone	200
Esopus gritty shales	800
Port Ewen shaley limestone including the Oriskany transition	250
Becraft crystalline limestone	75
New Scotland shaley limestone	100
Coeymans limestone	75
Manlius limestone including Rosendale, Cobleskill, and the cement beds	100
Binnewater sandstone	50
High Falls shale including small limestone layers	75
Shawangunk conglomerate	250 to 350
Hudson River slates — thickness unknown; probably more than	2000
Approximately	4775

These occur in belts in succession more or less regularly fron
west to east. Most of the formations are quite uniform in the
Rondout valley. The Shawangunk conglomerate is probably more
variable than any other as shown by borings. Because of thi
general persistence of formation it is possible to estimate approxi
mately the depth at which any particular lower member lies if som
starting point can be identified. [For detailed description of the
formation, *see* pt 1]

Structure. The principal irregularities are structural, rather
than stratigraphic. The region on the west side of the valley, the
margin of the Catskills, is but slightly disturbed and lies very flat,
but the region on the east side, the Shawangunk mountain range
and the cement district, has an extremely complicated structure.
The Rondout valley, lying between them, is a transitional zone and
passes from gentle dip slopes and folds in the westerly side to
more frequent folds and thrust faults on the easterly side. In at
least two thirds of the valley it would appear from surface evidence alone that the formations would dip uniformly westward, the
only suspicion of additional complication being given by an occa-

A minor fold in the Binnewater sandstone and High Falls shale at High Falls on Rondout creek. (Photograph by Columbia University Summer School in Geology. 1907)

sional minor fold seen in the river gorge or an escarpment where the sedimentary character alone would hardly account for it [*see* pl. 24, High Falls]. Explorations have shown that the evidence of the minor structures is reliable and that disturbances occur at some places even to the extreme western margin.

Physiography. In spite of the drift cover which obscures many original inequalities it is readily seen that the prevalence of the gentle westerly dip over most of the area, together with the succession of so many different beds of varying resistance to erosion, have allowed the development of a succession of long dip slopes and steep escarpments on a more pronounced scale than the present topography shows. It is clear that the Rondout is really a series of these unsymmetrical valleys. The principal large dip slopes are formed by the Shawangunk conglomerate and the Onondaga limestone. In each case an original stream had adjusted its course fully to the structure and was shifting slowly by the sapping process to the west against the opposing edges of the overlying strata which form the bordering escarpment. One of these unsymmetrical valleys lies along the easterly base of the Hamilton escarpment and is continuous with the lower course of Esopus creek farther to the north. In the area under special study it is not occupied by a stream now but is filled with glacial drift so completely that the original stream has been evicted. It is evident, however, from computations based upon the average dip of the slope carried to the base of the escarpment that the bed rock floor ought to be from 200 to 300 feet below the present surface in the deepest portion. Borings have proven this to be the case both along the present line near Kripplebush and also on the first trial line across the Esopus at Hurley.

The same thing is true near High Falls in the center of the valley where Shawangunk conglomerate forms the dip slope and the escarpment is formed by the Helderberg limestones. In this case the drift filling is very deep also, and Rondout creek flows upon it quite independent of rock structure except where it has cut across the margin as at High Falls.

In the eastern half of the valley the hard Shawangunk conglomerate forms the chief rock floor and largely controls the contour by its own foldings and other displacements. Thus the Coxing kill tributary valley lies in a syncline of the conglomerate with occasional remnants of overlying beds as outliers adding some variety to the form. The Shawangunk mountains, as a physiographic

feature, owe their present elevation chiefly to the resistance of this conglomerate which serves as a protective member among the formations.

On the west side, the foothills of the Catskills form a part of the cuesta developed by the erosion of Paleozoic sediments, the inface coinciding with the escarpment along the lower Esopus and Rondout valleys at this point.

It is certain therefore that the drainage of the Rondout valley before the Ice age differed materially from the present lines. A stream, probably the original Rondout, followed near the western margin of the valley and joined the Esopus as it emerged from the Hamilton escarpment to turn northeast. Another which had cut somewhat deeper occupied the central portion of the valley and probably joined the Esopus at some point farther north — its lower course is not explored.

Practical questions

The chief practical questions to be given as full answers as possible are:

1 At what depth must the aqueduct tunnel be placed in order to be everywhere in substantial bed rock with sufficient cover to be safe?

2 Where are the most critical places — those whose geologic characters are such as to demand exploration? And at the same time which sections may be safely left without testing?

3 What is the rock structure and condition? And are there reasons for believing that the tunnel plan is not feasible at this point. If so, where can a better one be found?

4 What is the character of underground circulation of water?

5 What formations will be cut at the different points and which should be favored or avoided wherever possible?

From the fact that the present Rondout flows across solid ledges at High Falls and at Rosendale from 100 to 200 feet above the known rock floor of the preglacial gorge where explored it is clear that the present course is entirely different from the original. The Coxing kill, the third and most easterly of these streams is not so much disturbed although it also is shifted.

It is worth noting that the streams of this valley together with the lower Esopus and the Wallkill river have become so completely adjusted to the rock structure that they all flow up the larger Hudson valley, of which all form a part, and join the master stream

at an obtuse instead of the usual acute angle. They are essentially retrograde streams.

Explorations. Systematic explorations and tests are represented chiefly by drill borings through drift into the rock floor. These were supplemented by two test tunnels for working character of material and a series of tests on the behavior of certain of the drill holes, together with other tests on material. The results are embodied in the accompanying cross sections and the additional discussion of special features.

Detail of local sections

Kripplebush section. This from the first was regarded as one of the critical sections because of the buried gorge along the base of the Hamilton escarpment and because of the doubt as to the behavior of the Onondaga limestone. On the accompanying section the borings are plotted and the structure as now interpreted is indicated. The dip slope formed by the Onondaga limestone is covered by 200 to 250 feet of drift, mostly modified drift. The strong valley character of the rock floor is almost wholly obscured by the glacial deposits and the present brook, an insignificant stream compared to the preglacial one, occupies a position above the escarpment instead of above the old channel.

After a couple of the central holes were finished, it became apparent that the structure is not nearly so simple at this point as the general surface features would lead one to expect. It was clear that a simple dip such as was proven to prevail on the dip slope would not account for the much greater depth attained by it in the vicinity of station 500. The discovery of this additional feature raised two questions: (1) Is the structure a flexure or is it a fault, and if a fault whether normal or thrust, and (2) what is the probable effect of this structure on the position and depth of the preglacial gorge?

The habit of the district immediately east of the valley would support the theory of a thrust fault. The nature of the immediate area would suggest a simple flexure while it is manifestly possible that a normal fault could easily occur. Later explorations[1] have

[1] Since the above was written the tunnel has been completed through the Kripplebush section. Although faulting is indicated by the borings and actual occurrence of the beds it is very difficult to find the fault. A part of the displacement is accomplished by the steepening of the dip but this will not account for more than half of it.

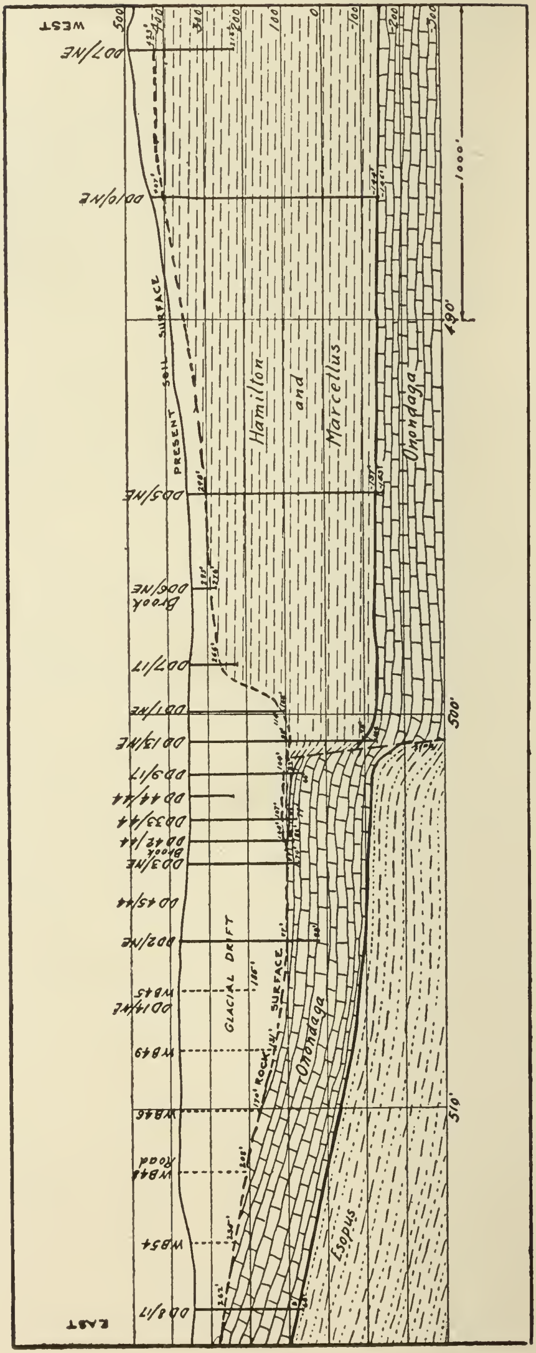


Fig. 19 Geologic cross section of Kripplebush section of the Rondout tunnel line as interpreted from drill borings

tested this zone so well that it is practically certain that the feature must be regarded as a fault of some type with a displacement of nearly 200 feet. The striking physiographic feature is the development and preservation of the escarpment on the downthrow side. This occurrence is certainly a very unusual case in that regard [*see* fig. 19].

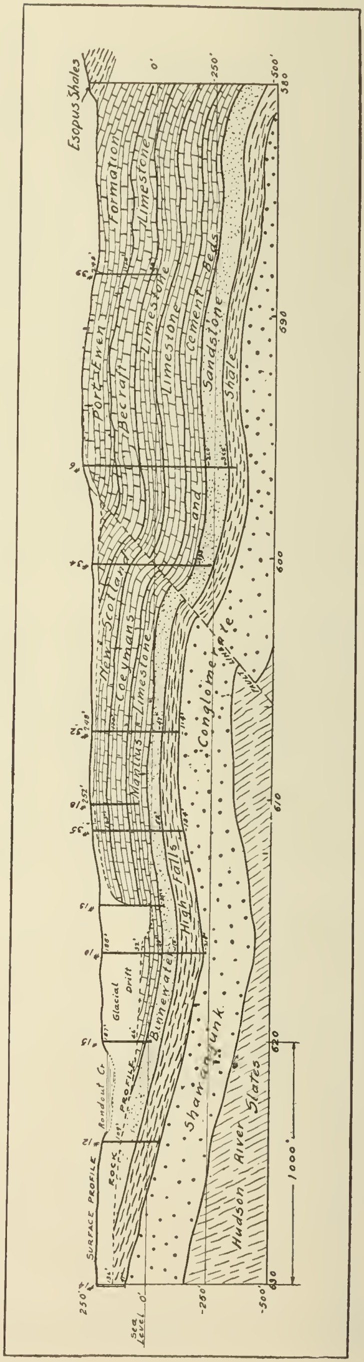
Because of the intention to construct the tunnel deep enough in bed rock to reach safe rock conditions the question of depth of buried gorge becomes an important one. As soon as it was discovered that a fault existed there the problem became of sufficient prominence to demand more detailed exploration. If the faulting is accompanied by a broken zone in condition favorable to more ready erosion, it would be possible that the original stream in working down this dip slope might become entrenched in the fault zone and at that point begin to cut a narrow gorge instead of continuing the sapping process. In fact, it would undoubtedly do this very thing if there is such a crushed zone of any consequence and if the erosion process were allowed to continue long after reaching this critical point.

As a matter of fact explorations have shown that there is a thin layer of Hamilton shales still remaining on the Onondaga and the deepest point found is on the Hamilton shales side. These facts in connection with the failure to find any deep notch indicate that there is probably no zone of much greater weakness than the shale member itself. It is reasonable to conclude that the rock floor can be safely regarded as not much lower than 88 feet A. T. and that the rock condition is not especially bad for tunnel construction[1] even in the fault zone.

Rondout creek section. This is the central portion of the valley including the depression occupied by the present Rondout and the exposed edges of the series of shales and Helderberg limestone. The repetition of the dip slope and escarpment, together with the heavy drift filling and the occurrence of so many formations together make this an important section. All formations from the Shawangunk conglomerate to the Port Ewen shaly limestone occur at this point, and although there is little outward evidence of disturbance it is certain that whatever difficulty is to be found in this variable series is likely to be met here. It is therefore a section that requires exploration both for depth of preglacial channel and for quality of rock.

[1] In construction this ground has proven to be good and sound throughout.

WEST



EAST

Fig. 20 Geologic detail of the central Rondout section constructed from exploratory borings data

All of the formations dip westward wherever exposed, but the dips vary somewhat, nearly all being of low angle. Occasional minor inequalities of the nature of small rolls may be seen, as, for example, the small fold in the gorge at High Falls [*see* pl. 24].

Explorations have shown, as indicated on the accompanying cross section [fig. 20], that there is a deeper buried gorge here than at Kripplebush. The deepest point discovered is a few feet below tide level. The escarpment is steep and is formed by the Coeymans and New Scotland formations. The dip slope is Shawangunk conglomerate, High Falls shale and Binnewater sandstone, with the Manlius limestone forming the floor.

Identification of the drill cores which penetrate the limestone indicate that the dip slope is reversed on the west side of the gorge and that the stream had really reached about the axis of the trough. A discrepancy in thicknesses and depths in hole no. 34 by which it appeared that the Coeymans formation was almost twice as thick as usual and that it contained a broken or crushed zone leads to the interpretation that there is a small thrust fault here which repeats the formation as shown on the accompanying cross section.

Instead of a uniform westerly dip of all formations from the Rondout westward it is proven that minor anticlinal rolls and even thrust faults, as in this case, or such faults as in the Kripplebush case are not to be excluded.

This structural relation has a direct bearing upon the question of the thickness of the Esopus shales. The Esopus is certainly not so thick as would otherwise be supposed, by 200 or 300 feet at the least. The true thickness is still an unknown quantity (estimated at 800 feet).

It is clear that the aqueduct tunnel will have to be constructed a considerable depth below sea level at this section, probably not less than minus 150 feet,[1] even if the character of the formations be neglected.

But the character or quality of these formations in view of their structural relation constitutes the chief problem. Because of the fact that every structure reaches the surface and eventually dips gently to the west in such manner as to encourage water circulation, their water-carrying capacity or general porosity becomes of great importance. A great capacity is all the more serious because of the heavy drift cover within the abandoned gorge, on top of which

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[1] This portion of the tunnel and its continuation south to the Shawangunk range has been constructed at 250 feet below sea level.

the stream flows and which constitutes essentially an unlimited storage reservoir to feed underground circulation. This is all the more true if crush zones are extensively developed as accompaniments of the faulting.

In general as to perviousness the indications are somewhat obscure. But the data now obtained seem to prove that all the formations except the Binnewater sandstone and the High Falls shale are compact and fairly impervious along the bedding lines. Only where crevices have formed or where crushing occurs is there likely to be heavy circulation. This is all the more important since so many of the beds are limestones known to be readily soluble in circulating water. One of these limestones, the Manlius, exhibits occasional large open solution joints at the surface — so large that a surface stream disappears entirely at the so called "Pompey's cave" and joins the subterranean circulation. But such caves are probably limited to the surface.

It is near this point, however, that one of the earlier borings at one side of the present line discovered very soft ground at a depth of about sea level, i. e. over 200 feet below the present surface, which shows that similar conditions prevail at certain points to great depth.

Pumping tests made on hole no. 32 in an attempt to establish some data on the inflow of water gave very interesting results. These tests were very thorough. It was proven that the water was supplied in apparently inexhaustible quantity at maximum pumping capacity, which was ninety gallons per minute. Futhermore, the chief inflow seemed to be from the Binnewater and High Falls formations as was to be expected. Whether a crush zone allowing free circulation is furnishing a portion of this supply or whether the whole inflow represents the normal porosity condition of these formations is not yet proven.[1]

Other porosity tests have been made in such way as to locate and measure this factor [*see* later discussion]. Hole no. 10 shows an artesian overflow that comes from the Binnewater sandstone. A working shaft has been put down also in the vicinity of hole no. 32 and at the same depth found an enormous inflow of water which drowned out operations for a time. The lateral supply in this case has been reduced by introducing a thin cement grouting through holes bored in the surrounding rock from the surface.

Holes no. 12 and no. 14 also show an artesian flow, but both are

[1] In construction the Binnewater sandstone has been found very wet.

shallow holes and the supply comes from near the contact between High Falls shale and Shawangunk conglomerate.

It is certain from these observations and tests therefore that the Binnewater sandstone and High Falls shale are more porous than the other formations, and because of the serious difficulties arising from so heavy inflow of water from them the tunnel grade should be shifted so as to avoid these formations as much as possible. A comparison of the accompanying cross section, which is drawn to scale [fig. 20], will show that a tunnel on one level would necessarily run for a long distance in these beds because of the gentle syncline. Furthermore, they lie at about the depth that would otherwise be a safe depth below the buried gorge. But a tunnel with a step-down, i. e. one run at two different levels could avoid most of this poor ground. By approaching at a level of about — 50 feet or — 100 feet in the limestone beds to station 600 (hole no. 34), then stepping down to — 250 feet, the line in a very short distance crosses these two porous formations and enters the Shawangunk conglomerate which is more substantial, and, all things considered, one that seems most advantageous for successful construction. It will have to maintain a head of more than 700 feet as the difference between hydraulic grade and the tunnel level in this section. Under these conditions rock quality and condition are of greatest importance and there is no doubt about the advisability of avoiding the poorest formations in some such manner.

Coxing kill section. On the line of exploration the Coxing kill flows over Shawangunk conglomerate and High Falls shale. Both dip plainly eastward, and a hole no. 11 located on the east side of the brook penetrates about 70 feet of drift and shale. But only a hundred feet to the east Shawangunk conglomerate outcrops at the surface dipping the same way. It is certain therefore that a fault occurs here. The dip of the fault plane is indeterminate from the surface, but the relations and surroundings indicate a fault of the thrust type.

Later explorations indicate that the fault plane is rather flat [*see* cross section fig. 21] so that the shales are repeated above and below a tongue of conglomerate. Boring no. 11 has also an artesian flow of considerable volume coming from near the bottom of the conglomerate. It is a mineral water.

The chief importance of this section as a problem in applied geology lies in the influence of the fault and the maximum depression of the conglomerate. If the tunnel, which enters Hudson River slates at the Rondout creek section at — 250 feet can be kept within that formation throughout the rest of its course,

there is no doubt that an advantage will be gained both in the greater imperviousness of the rock and the greater case of penetration. Wherever the conglomerate is undisturbed it is perfectly good, but where broken the crevices are but imperfectly healed and circulation is unhindered. It would therefore be desirable to know whether at — 250 feet the whole of the downward wedge of Shawangunk could be avoided. The borings indicate a thickness of Shawangunk of 345 feet in hole no. 11 where it is cut at a small angle, and a thickness of 409 feet in hole no. 36 where it probably lies pretty flat. This greater thickness together with the

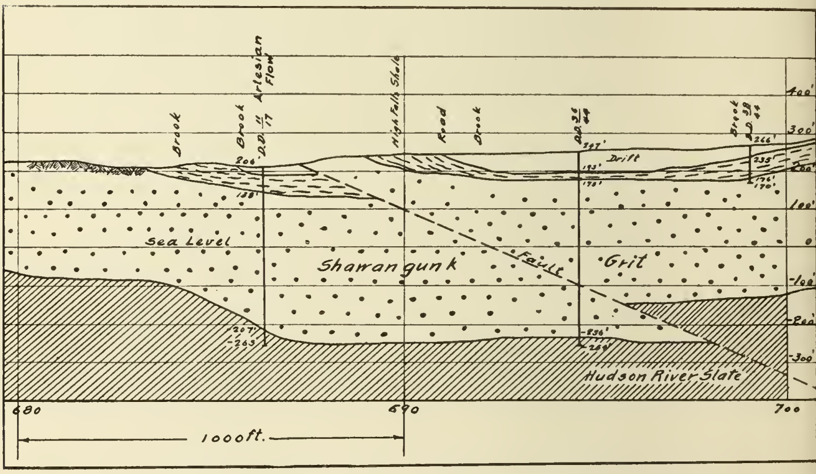


Fig. 21 Structural geologic detail of the Coxing kill section

finding of crushed rock at about the — 100 foot level leads to the conclusion that the formation is overthickened here by the thrust fault to the extent probably of about 75 feet. The true thickness of the formation at this point is doubtless more nearly 300 feet than either of the figures obtained directly from the two holes. If this interpretation is used as the basis of plotting a cross section [*see* accompanying cross section] it is apparent that the conglomerate should not be expected to extend more than a few hundred feet east of hole no. 36 and it probably does not reach a much greater depth than the — 236 feet represented as its base in that boring.[1]

[1] Construction of the tunnel has progressed far enough through this section to prove that the Shawangunk formation does not reach much lower. It forms the roof of the tunnel for some considerable distance but does not come down into the tunnel more than a foot or two.

Shawangunk overthrust. At the extreme eastern side of the Rondout valley near the point where the surface reaches hydraulic grade again, the surface outcrops pass from High Falls shale to Shawangunk conglomerate to Hudson River shale in the normal order but with entirely too small an area of conglomerate considering the character of the formations. The higher ground is all Hudson River in the vicinity, and there is abundant evidence of crushing and disturbance. It is evident that a thrust fault is again encountered here, one of sufficient throw to bring the Hudson River slates above the Shawangunk conglomerate — probably a lateral displacement of very great extent. Explorations have fully proven the existence of this fault. The accompanying diagram shows a cross section as now outlined by complete penetration of two borings.

Two trial tunnels were run to test working quality of Hudson River slates compared to Shawangunk conglomerate at this locality. Both are within the influence of the fault zone. Both are therefore more broken than the normal with the result that the Hudson River slates probably show poorer condition than usual and more troublesome working, while Shawangunk conglomerate probably shows easier working than usual. It is believed that normally the two rocks would present a greater difference than was found in this test.

Special features

Several questions, some of which have a practical bearing, have been raised as separate features during the exploration of the Rondout valley.

Caves. One of these is in regard to the possible existence of underground caverns. This was given a special prominence early in the work by the experience of one of the drills. After penetrating the limestone series near High Falls to a depth of over 200 feet, the drill seemed to leave the rock and enter a space allowing the rods to drop 28 feet before being arrested by solid material. The further attempt to work in this hole resulted in the breaking of the rod down at this point and the subsequent failure to recover the diamond bit which is still in the bottom of the hole. The question is as to the meaning of this occurrence. Is it a cavern?

"Pompey's cave" has been referred to in an earlier paragraph. This is clearly not much of a cave. It is essentially an enlarged joint or series of joints by solution along the bed of a surface

stream to such extent that the stream normally at present has become subterranean. It is the writer's opinion that the case encountered by the drill boring is similar. The apparent cavern is probably a slightly enlarged joint along a line of somewhat abundant underground circulation and perhaps associated with some crush zone developed by the small faulting known to occur in this immediate vicinity. It is probably not entirely empty but contains residuary clay, and in all likelihood is very narrow and not exactly vertical, so that the drill rods were bent out of their normal course and wedged into the lower part of the crevice. Smaller spaces of this sort were encountered at a few other points.[1]

These occurrences seem to indicate that the limestone beds yield rather readily to solution by underground water, and that this circulation has been at one time active to at least 50 feet below present sea level. With present ground water level nearly 200 feet above sea level it is extremely unlikely that any such action is going on at so great depth. The occurrence is therefore strongly corroborative of former greater continental elevation when the deep stream gorges, now buried, were being made. These deeper caverns or solution joints probably date from that epoch.

Imperviousness and insolubility. The question of imperviousness and closely associated with it that of solubility, is of great practical importance in this particular work. The immense pressure under which the tunnel will be placed in crossing this valley makes it impossible to construct a water-tight lining. Everywhere much depends upon the rock walls to help hold the water from serious loss. Wherever the rock is fairly impervious except occasional crevices or joints they can be grouted and safeguarded satisfactorily. But where a formation is of general porosity this can not be so successfully done. Even more difficult to handle is the rock wall which is soluble and which therefore with enforced seepage may tend to become progressively more porous. That this consideration is not wholly theoretical is shown very forcibly by the Thirlmere aqueduct of the Manchester (England) Waterworks. In that case a 3 mile section was built through limestone country using the same local limestone for concrete aggregate. Although

[1] In constructing the tunnel several clay-filled spaces have been discovered in the same vicinity at elevation—100. One of these extended vertically with a width of 1 to 2 feet and from it a great mass of mud ran into the tunnel. At one point it was connected with a horizontal space of the same kind extending 15 feet. It can be seen that the original crevices have been enlarged by water and that they were originally formed during faulting.

this concrete was mixed as rich as 1 part cement to 5 parts aggregate and the work was well done, excessive leakage reaching a total of 1,250,000 imperial gallons per day was developed within a year. It was found that the limestone fragments of the aggregate were corroded forming holes through the lining of the aqueduct and that these holes actually enlarged outward. All this was done under cut and cover conditions with not more than a 6 or 7 foot head on the bottom of the aqueduct.

In the Rondout valley, the aqueduct will cut no less than 6 limestone beds in all cases under great pressure. This fact will in all probability tend to increase the action. But, of course, some of the beds may not yield so readily to solution. Tests made thus far, however, indicate that all are attacked in water. Considering these facts it seems desirable, so far as possible, to avoid the limestone beds wherever rock of greater resistance to solution can be reached, and further it is equally desirable to use a more resistant rock for the lining concrete. So long, however, as the formation is not very pervious so that a new circulation could not be established by the escaping water there would be little harmful effect.

An average of five analyses of the Thirlmere limestone, different varieties of the same formation, gives the following:

Insoluble silicious matter	2.772%
Alumina and iron oxid $Al_2O_3+Fe_2O_3$	0.276
Lime, CaO	53.676
Magnesia, MgO	.390
Carbonic anhydrid, CO_2	42.248
Total	99.362

Estimated calcium carbonate, $CaCO_3$ — 95.85%

The limestone is fossiliferous.

Suitable analysis of the limestones of the Rondout valley are not recorded in sufficient numbers. But these are a few, as given below.

BECRAFT LIMESTONE.	At Rondout	At Wilbur	At Hudson (av'ge of 2)
SiO_2	3.87%	7.10%	1.865%
Al_2O_3	1.07	2.50	.818
Fe_2O_3	1.34	1.65	1.185
CaO	54.11	45.32	51.375
MgO	tr	tr	2.870
CO_2	40.60	39.10	40.795
Total	100.99	95.67	98.908
Corresponding to total calcium carbonate	96.62	80.75	91.74

This is a limestone that in composition and structure at th Rondout valley is apparently not very different in quality from th Thirlmere rock. Analyses of the cement rock show less similarit but observations indicate that it is also attacked.

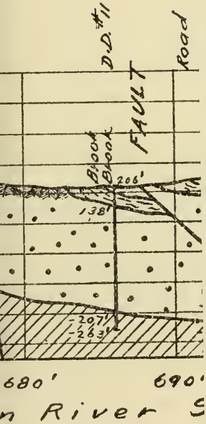
It is probable from all these facts that the shales and conglomer ates are better quality of wall than the limestones.

A very acute observation along this line by Dr Thomas C. Brow while employed on the staff of the Board of Water Supply is o special interest. In studying local conditions he noticed that th limestone blocks used in building the old Delaware and Hudso (D. & H.) canal showed the effect of contact with the water. Th best place for measurable data seemed to be around the old lock where squared and evenly trimmed blocks had been used. Thes were, during the years of its use, from 1825 (approximately 35 t 40 years) subject to the action of water flowing or standing i direct contact. The coigns of the locks, which were without doub freshly and well cut when laid, are now etched till the fossils an other cherty constituents stand out from one eighth to one hal inch beyond the general block surface, and in some cases the pit are an inch deep. That this etching is due to the water rathe than to exposure to weather is shown by the lack of such extensiv action on blocks used in houses and exposed a much longer time Blocks representing the Manlius and Coeymans were identified But there is no reasonable doubt that others would be similarl affected. On some it would be less easily detected.

On account of the disturbances another factor is introduced Rocks which readily heal their fractures are likely to furnish bette ground, i. e. more free from water circulation especially, than rock more brittle and slow to heal. Therefore in this district the shale and slates such as the Hudson River series and the Esopus an Hamilton shales are the best ground, while the Binnewater sand-stone is the poorest.

Cross sections. Probably in no region of like extent is it possible to construct a geologic cross section of so many complex features so accurately as can now be done of the Rondout valley along the aqueduct line. The section is known or can be computed to a total depth below the surface of 1000 feet, including 12 distinct formations, so closely that any bed or contact can be located within a few feet at any point throughout a total distance of over 4 miles.

The accompanying cross section contains as much of this data as is now available [fig. 22].


D.D. #11
Road
FAULT
Brook
Brook
206'
138'
-207'
-263'
680'
690'
River

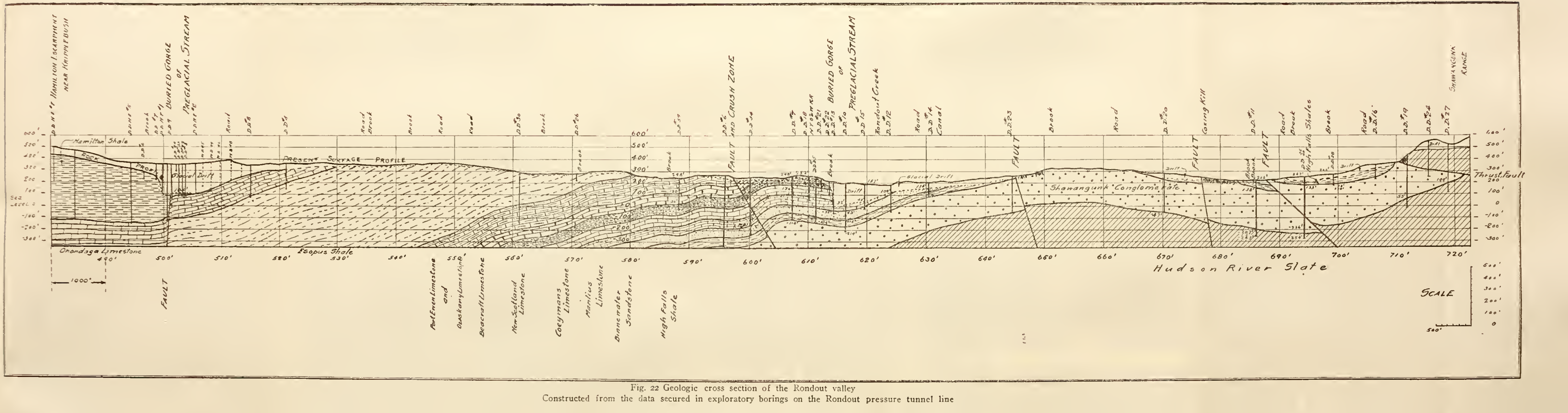


Fig. 22 Geologic cross section of the Rondout valley
Constructed from the data secured in exploratory borings on the Rondout pressure tunnel line

Rondout siphon statistics

1 **Total borings on the siphon line.** Three different boring equipments have been used owned by different parties and records have been kept so that the work of each can be followed or compared with the others.

On this division the Board of Water Supply owned and operated one machine with their own men, another equipment was owned and operated by C. H. McCarthy, while a third which finally did a majority of the work, belonged to Sprague & Henwood, Contractors, of Scranton, Pa.

The totals of different general types of material penetrated by these machines are as follows:

	Feet of drift	Feet of rock	Total feet of depth	Per cent of core saved
a B. W. S. Equipment	1740.5	2175.5	3916	89.4
b Sprague & Henwood	3647	6831	10478	60.04
c McCarthy machine	181	1228	1409	78.1

The average saving of core by all machines, cutting all kinds of bed rock was 75.96%

2 **Core recovery from various strata.** So nearly as can be done the strata represented in the drill cores have been identified and summarized as to total penetration and core saving. The core saving is a factor of prime importance in judging of the quality of rock and its freedom from disturbance. The following items are gathered from a study of the whole series.

a Holes 6, 10, 12, 13, 15, 17, 18, 21, 22 and 25 penetrate Helderberg limestone, a total combined depth of 1096 feet. Individual holes vary in core saving from 39.3% (no. 13) to 95.3% (no. 15). The average core saving is 78.19%.

b Holes 8 and 9 are in Onondaga limestone with a total penetration of 197 feet. The core saving varies from 56.2% to 92.8% with an average of 74.5%.

c Holes 11, 19, 20, 23, 24, 27 penetrate Hudson River shale and together represent a total of 696.5 feet. The core saving varies from 16.6% to 89%, with an average of 42.1%.

d Holes 6, 10, 11, 12, 14, 16 and 20 cut High Falls shales to a combined total of 410 feet. The saving varies in different holes from 17% to 83.3%, with an average core saving of 44.5%.

e Holes 8 and 26 penetrate Esopus shale and penetrate 76 feet.

The core saving varies from 73% to 84.6%, making an average of 78.8%.

f Holes 10, 11, 12, 14, 16, 19, 20, 23, 24 and 27 penetrate Shawangunk conglomerate a total of 1356.5 feet. Core saving varies in different holes from 33.3% to 100%. The average recovery is 60.52%.

g Holes 6, 10, 12, 15 and 16 cut Binnewater sandstone. The total penetration is 205 feet. The range of core saving is from 30.6% to 74.7%, with an average of 56%.

h Holes 7 and 9 cut Hamilton shales to a total amount of 65 feet. The range of saving is 70% to 81.8%, with an average of 75.9%.

3 **Artesian flows.** Several of the borings struck artesian flow of water. The fact that the sources of this flow are not the same has led to a tabulation of these data.

RECORD OF ARTESIAN FLOWS

Hole no.	Size in inches	Static head in feet	Flow gallons Minute	Flow gallons Day	Flow encountered at elevation Feet	Strata
10	1	18	30	43 200	—109	....Binnewater sandstone
11	1	10	10	14 400	— 60	....Shawangunk conglomerate
12	⅜	1	....	......	— 24	....High Falls shales
14	1¾	......	....	......	+ 90	.... "
20	⅜	7.5	10	14 400	+108	....Shawangunk conglomerate
23	2	......	....	......	— 5	.... "
31	2	......	....	......	+158	.... "
39	1½	......	....	......	+112	....Helderberg limestone
5NE	⅜	12.4	....	432	+203	....Hamilton shale (possibly drift)

Pumping experiments and porosity tests

Systematic tests have been made for flow of water, behavior of ground water and porosity of rock on certain of the Rondout exploratory holes under the direction of Mr L. White, division engineer. A summary of these tests has been furnished by him from which is quoted the following:

In addition to determining the location and thickness of the beds and the general character and condition of the rock from inspection of the cores, serious attempts were made to determine the relative porosity and water-bearing quality of the rocks encountered for the following reasons. (1) To determine the probable leakage from the siphon when in operation. (2) To determine the probable amount of water to be handled in construction. These experiments were divided into three classes: (1) Observation of flow from cer-

tain drill holes which showed sustained flow of water. (2) Pressure tests in which water was pumped into holes which had been sealed off and pressure and leakage noted. (3) Pumping tests in which water was pumped from 4 inch drill holes by means of deep well pump of the type used in oil wells, and fall of ground water during pumping and subsequent rise after cessation of pumping noted. A description of the first two and the results obtained from them follows:

A substantial flow of water was observed from the following holes:

11/17: 50 gallons per minute through 2½ inch pipe, static head 10 feet

10/17: 30 gallons per minute through 1½ inch pipe, static head 18 feet

20/17: 10 gallons per minute through ⅜ inch pipe, static head 7.5 feet

The static head was observed by adding on lengths of pipe until the water ceased to flow over. It will be noticed in the case of hole no. 10 that the flow from the 1½ inch pipe is not that due to static head of 18 feet, but that due to a head of only ½ foot. In other words the friction head is about 17.5 feet, and the velocity head only ½ foot. This same condition holds true of the other holes from which a flow was obtained. This would seem to indicate that the amount of water is not very great but that it is under considerable pressure. It is believed that this pressure is caused by gas.

A slight flow was observed from the following holes: 12/17, 14/17, 23/17, 31/44, 39/22, and 5/NE.

The flow from most of these holes has ceased since the pipe used in boring was withdrawn. There is still some flow from the following holes: 11/17, 20/17, 25/17 and 5/NE.

The flow from hole 11/17 is constant at about 10 gallons per minute. The others are too small to be measured. It will be noted that the only substantial flows encountered were from the High Falls shale, Binnewater sandstone and Shawangunk grit, and that it was possible to force water into these rocks in greater quantities and at a less pressure than in the other shales and limestones.

Porosity tests. The method of making these tests was as follows:

Wash pipe equipped with a device for sealing the hole was lowered to the desired elevation. The seal consisted of alternate layers of rubber and wood around the pipe preventing the water from escaping between the walls of the hole and the pipe. Water was then pumped in and pressure and leakage noted.

The result of the pressure tests was to show in a general way: (1) That the pressure increased with the depth of seal. (2) That the leakage decreased with the depth of seal. (3) The maximum pressure in the grit was 140 pounds to the square inch and minimum

leakage was 5 gallons per minute. (4) In the Hamilton shales a pressure of 300 pounds to the square inch with very little leakage was obtained.

The unknown factors are too many and too great to make any reliable deductions from these experiments.

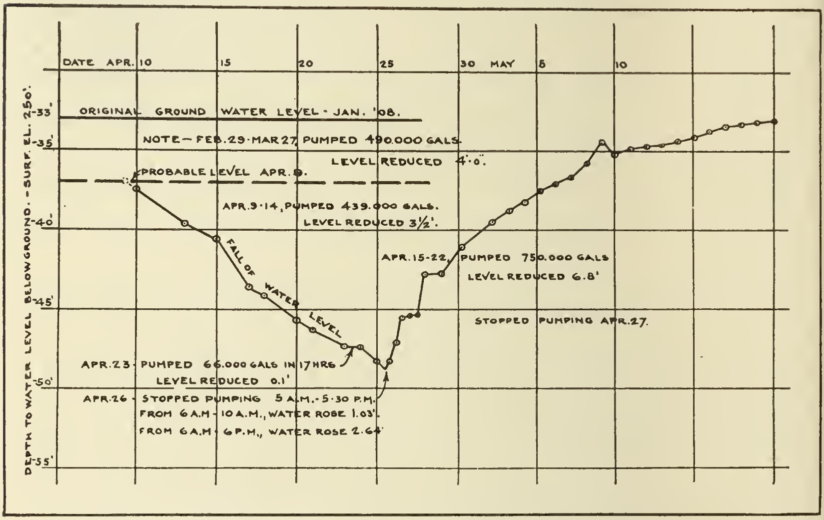


Fig. 23 Curve showing fall of ground water level while pumping from boring 34

Pumping experiments were carried on in holes 32/22 as follows: The apparatus used was a deep well pump of the type used in oil wells. The holes were of an inside diameter of 4¼ inches and were cased to the bottom. A 3½ inch working barrel was then lowered to the bottom of a line of wooden sucker rods. The stroke was 44 inches and the nominal capacity of pump at 38 strokes per minute was 60 gallons per minute or 86,400 gallons per day. The power was obtained from a 40 horsepower boiler and 35 horsepower engine belted to a 10 foot band wheel which was connected to a 26 foot walking beam. In hole 32/22 at station 607 + 50 the average discharge at 38 strokes per minute was 90 gallons per minute or 129,600 per day. The experiment was continued for 15 days and the total amount of water pumped was 1,071,000 gallons. The ground water level was not lowered. It will be noticed that the discharge at this point was 50% in excess of the theoretical capacity of the pump. This was caused by the presence of gas, the effect of which seemed to be increased by the churning action of the pump. This may also explain the failure to lower the ground water.

The experiment at hole 34/22 was similar in character. The upper 230 feet of this hole had an interior diameter of 4¼ inches

and the bottom 274 feet a diameter of only 3¼ inches. At first a 2¼ inch working barrel was used to pump from the bottom and a discharge at 32 strokes per minute averaged 24 gallons per minute or 34,500 gallons per day. This was continued for about 15 days and the total quantity pumped was 490,000 gallons. The ground water level was lowered 17 feet at hole 34 and 4 feet at hole 32, 750 feet away.

The 3¼ inch pump was then let down to a depth of 200 feet with a 2½ inch casing reaching down to the Binnewater sandstone, depth of 437 feet. The average discharge at about 40 strokes per minute was 60–65 gallons per minute, or an average of 90,000 gallons per day. It will be noted that the discharge was much smaller than at hole 32 owing to the absence of gas. Pumping with a 3¼ inch pump was continued 16 days and 1,532,000 gallons of

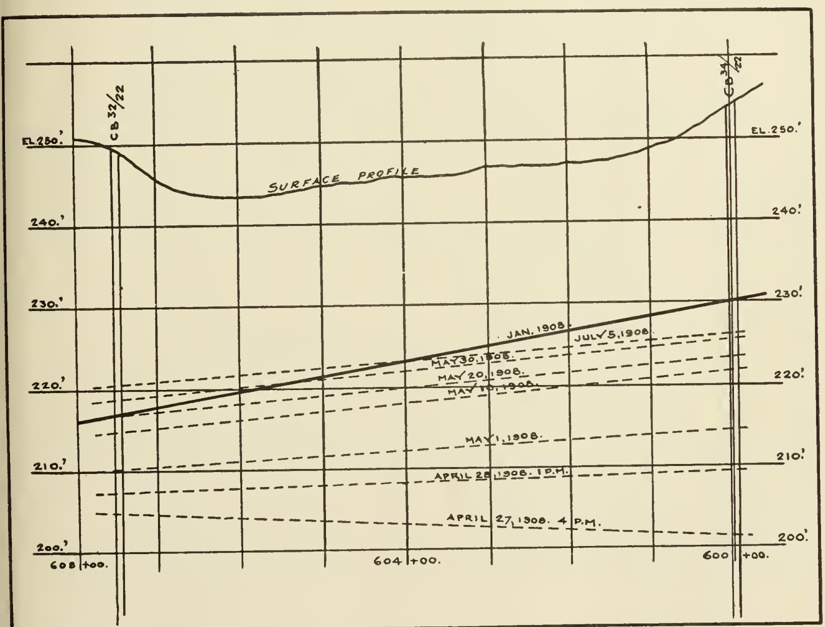
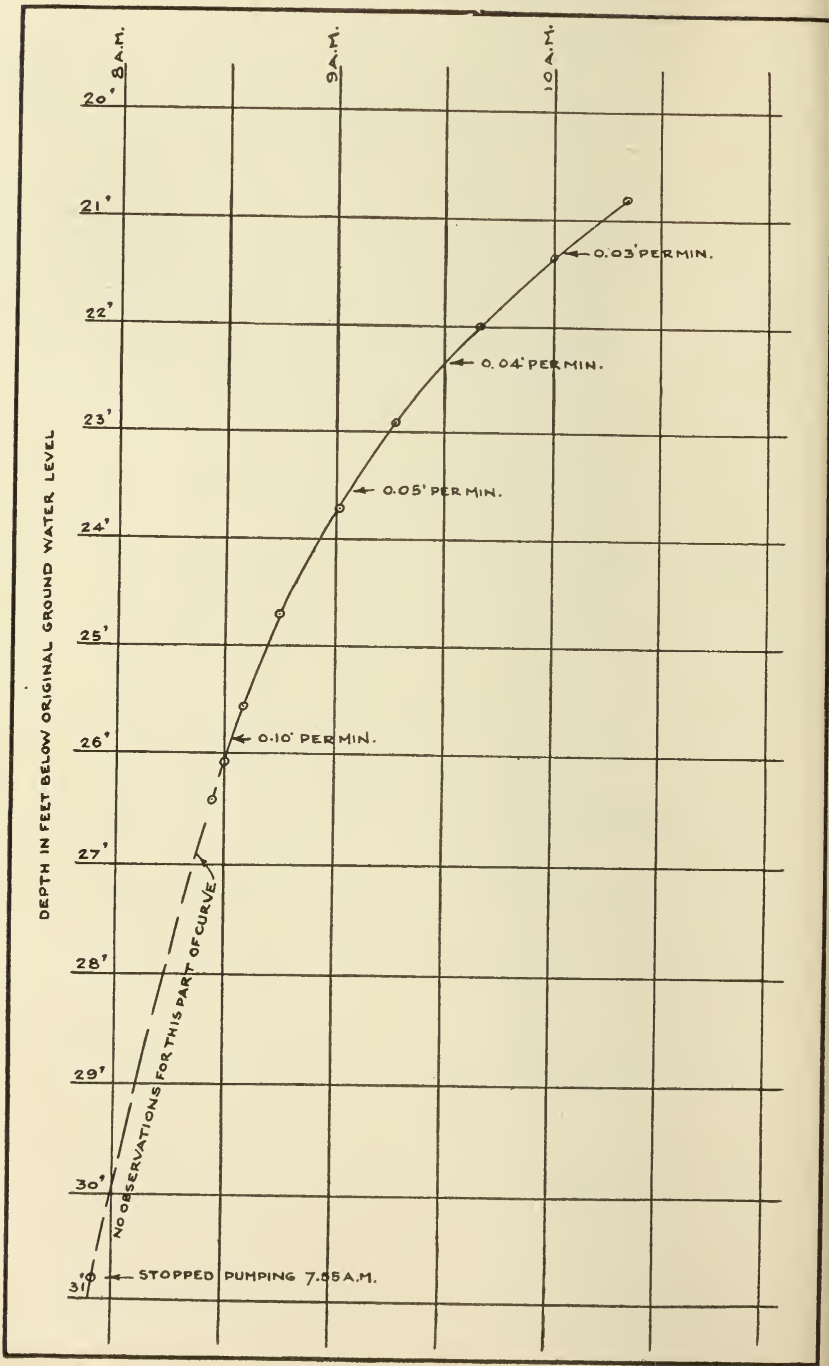


Fig. 24 Diagram showing successive stages of ground water level between holes 32 and 34 during pumping

water were pumped in addition to the 490,000 gallons from the 2¼ inch pump. The ground water level in hole 34 was lowered 36 feet in addition to the 17 feet by the 2¼ inch pump, but rose 9 feet in 20 minutes, and 30.5 feet in the next five days. In the next 22 days it rose 9.15 feet, or .42 feet per day.

Reduced water level in hole 32, 750 feet away by pumping in 34, 15 feet, or 1 foot for each 120,000 gallons pumped. In the first


8 A.M.
9 A.M.
10 A.M.
20'
21'
22'
23'
24'
25'
26'
27'
28'
29'
30'
31'
DEPTH IN FEET BELOW ORIGINAL GROUND WATER LEVEL
0.03' PER MIN.
0.04' PER MIN.
0.05' PER MIN.
0.10' PER MIN.
NO OBSERVATIONS FOR THIS PART OF CURVE
STOPPED PUMPING 7.55 A.M.

three days after pumping ceased water rose 5.2 feet, and in 22 days rose 9.8 feet or at the rate of 0.45 feet per day.

During construction[1] shaft 4 located at same point as hole 32/22, station 607 + 50, has proved a very wet shaft, the inflow varying from 400 to 850 gallons per minute. Pumping at this shaft has lowered the general water level and correspondingly lowered the water level in hole 34/22 at station 600 + 00.

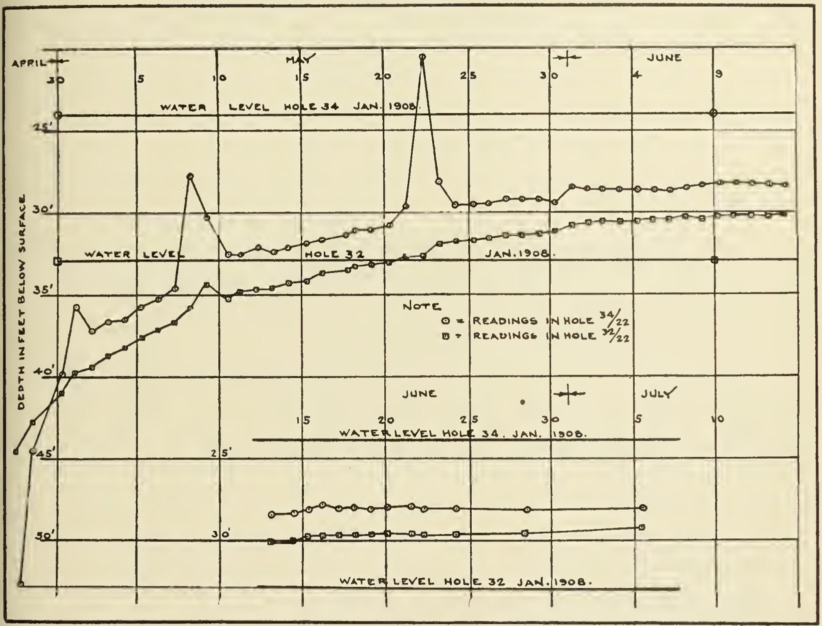


Fig. 26 Curve showing rise of water in holes 32 and 34 after pumping ceased in hole 34

[1] From this shaft after reaching tunnel grade,— 250 feet, and after running northward into the fault zone and porous shales, the contractors are pumping 1300 gallons per minute.

CHAPTER VII

THE WALLKILL VALLEY SECTION

Between the Rondout and Wallkill valleys the aqueduct is to follow a tunnel at hydraulic grade which so far as can be seen will cut only Shawangunk conglomerate and Hudson River slates. No doubt there are many complicated small structures which because of the nature of the slates can not be reconstructed. The work of tunneling is not advanced far enough to add anything. But in the Wallkill valley, where it is necessary again to plan a pressure tunnel several hundred feet below grade, a considerable amount of exploration has been carried on.[1]

These explorations [*sec* sketch map fig. 8] are distributed along several lines crossing the valley at intervals between Springtown, about 3 miles north of New Paltz, and Libertyville, which is about an equal distance south.

The geology is simple. Only Hudson River slates form the rock floor, and so far as can be judged no other formation is likely to be cut by the tunnels. There are no doubt many complicated structures, both folds and faults, as indicated by the high dips, but again because of the nature of this rock it is impossible to discriminate closely enough between different beds to determine exact relations. The point of greatest practical importance lies in the fact that the rock is fairly uniform and, although much disturbed is of such nature that crevices and joints or fault zones are almost as impervious as the undisturbed rock. This is because of the tendency of a formation of this composition to heal itself with fine, compact clay gouge. In fact, the mechanical disturbance produces or develops the cement filling contemporaneously with the movement. It is chiefly a mechanical filling, whereas the healing of a harder and more brittle rock like a granite or a limestone requires more chemical assistance.

An additional practical question involves the estimate of depth required to avoid any possible buried Prepleistocene gorges and maintain a safe cover to guard against undue leakage or rupture.

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[1] Explorations on the Wallkill division are carried on under the direction of Lawrence C. Brink, division engineer. The final construction is in charge of James F. Sanborn, division engineer, with headquarters at New Paltz, N. Y.

To this end most of the explorations were made. Two lines less than a mile apart on which a few exploratory borings were made near Springtown indicate two buried channels, a master channel and a tributary from the west which converge northward. A maximum depth reaching 70 feet below sea level was found on the more northerly line almost directly beneath the present stream channel which flows on drift at an elevation of 150 above tide.

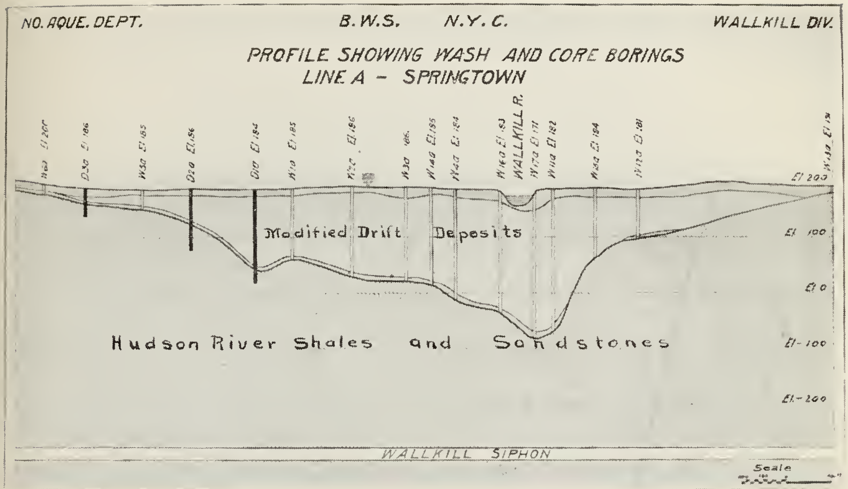
The more southerly profile reaches only sea level indicating a gradient for the preglacial stream at this immediate locality of more than 79 feet per mile.

In the vicinity of Libertyville, 5 to 6 miles farther south, where the aqueduct was finally located, the profile was found to be considerably higher. Intermediate profiles are shown in accompanying figures. The deepest point yet found on the Libertyville line is 65 feet above sea level. It is worth noting that the gradient of the ancient Wallkill is therefore shown to be decidedly unsymmetrical. The rock floor formation remains the same although it may vary somewhat in character. Under these circumstances, however, a gradient of 13 feet per mile from Libertyville to Springtown forms a sharp contrast with the 79 feet per mile represented at the Springtown locality. In view of the remarkable increase of gradient and the narrower form it seems reasonable to regard this as a rejuvenation feature developed at the time of extreme continental elevation.

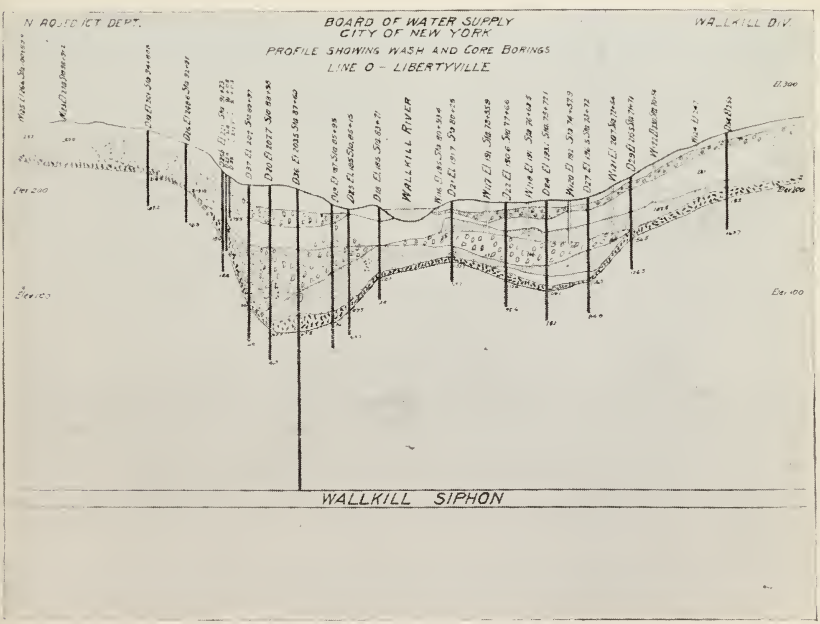
How much deeper the lower Wallkill may be, including the so called Rondout river, which is really a continuation of the ancient Wallkill and geologically belongs to this drainage line instead of to the Rondout, no one can tell. But it is at least interesting to observe that the intervening distance from Springtown to the Hudson at Kingston is approximately 12 miles and that a gradient for that distance equal to the average known in the 6 miles explored, i. e. 24 feet per mile, would depress the outlet 288 feet more. That would be equivalent to 367 feet below sea level. If, however, a steep gradient such as that at Springtown prevails in this lower portion it is necessarily much lower — for example if a 79 foot gradient is maintained it would be possible to reach a final outlet at —1029 feet. It is likely that an intermediate value is more nearly correct. This has, however, an important bearing upon the question of maximum Hudson river depth, especially the existence of an inner deeper gorge above the Highlands. So far as this Wallkill profile goes, it supports the gorge theory. It is certain that the Prepleistocene Wallkill flowed north not very dif-

The Wallkill valley looking toward Bronticou Crag in the Shawangunk mountain range. (Photograph by Board of Water Supply)

Plate 26



Cross section showing the buried preglacial Wallkill channel as indicated by exploratory borings near Springtown



Profiles of the present and preglacial Wallkill channels near Libertyville, and a diagrammatic section showing the different types of drift-filling together with the borings which furnished the data

ferently from the present stream except on a steeper gradient, but in all probability the headwater supplies between this stream and the Moodna have been somewhat shifted. It is possible that some former Moodna drainage area is now tributary to the Wallkill. But these changes were wholly glacial in origin and the extent of such shift is indeterminate at present.

It is a notable fact that a large proportion of the work of exploration in this valley was done successfully by the wash rig.

The extensive lot of data was gathered without much delay or difficulty. This is because of the nature and origin of the drift cover. A considerable proportion of the drift mantle especially in central and deeper portion of the valley is modified assorted sands, gravels and silts or muds. In part they represent deposits in standing water laid down at a time when the lower (north) end of the valley was obstructed by ice and while waste was poured into the valley from neighboring ice fields. It is impossible to reconstruct the beds of these materials with any degree of accuracy. But it is at least certain that lens or wedgelike layers of different quality of material were penetrated, indicating oscillation and overlapping of deposition conditions, boulder beds and till being interlocked with assorted sands and gravels. But there is apparently no evidence of ice deposits of greatly differing age. The accompanying profile and cross section is a representation of materials on the Libertyville line based upon identifications made by the inspector of the Board of Water Supply of the Wallkill Division under Mr L. C. Brink, division engineer.

CHAPTER VIII

ANCIENT MOODNA VALLEY

Moodna creek enters the Hudson from the west between Cornwall and Newburgh not more than a mile north of the entrance to the Highlands. It is a retrograde stream in its backward flow similar to the Wallkill. But its channel at present is almost wholly on glacial drift which it has trenched to a depth of more than 100 feet below the average adjacent surface. How much of its retrograde course therefore may be postglacial is not so clear. It seems necessary, however, to account for all drainage on the north margin of the Highlands by streams flowing to the Hudson northward. There is no notch low enough for their escape elsewhere. The ancient Moodna must have carried most of this run-off from the district occupying the angle between the Wallkill and the Highlands. This stream may have drained even more of the region now forming the divide with the Wallkill than does the present Moodna. In any case it must have been a stream of considerable size, capable of excavating a valley or gorge of greater prominence during the period of early Pleistocene rejuvenation than now appears. Furthermore its position makes it highly probable that tributaries of fair size entering in its lower course were also effective enough to require consideration. This conclusion has led to the exploration of the Moodna valley in considerable detail in preparation for the aqueduct work.

The Catskill aqueduct is to cross the stream near Firth Cliffe, which lies almost directly west of Cornwall-on-Hudson, and because of the low surface elevation across this valley, as in the others, a pressure tunnel in rock is judged to be the most suitable type of structure. The accompanying sketch map shows the location.

Explorations were conducted especially for the buried channels and character of rock floor.

Geologic features

The region is one of chiefly Hudson River slate. But there are inliers of the older rocks such as Snake hill which belongs to a long ridge of Precambric gneiss and granite, brought to the surface by folding and faulting and there are more rarely outliers of younger formations such as Skunnemunk mountain. Farther north

at Newburgh a gneiss ridge is accompanied by limestone, but in its southerly extension the slates are in direct contact. This relation is believed to be wholly due to faulting on both limbs of the anticlines. This gneiss ridge disappears southward beneath the drift, but the borings have shown that it continues across the aqueduct line, although it has lost its influence on the topography. There are other inliers of similar character such as Cronomer hill 3 miles northwest of Newburgh. Between these two gneiss ridges lies the southerly extension of the Wappinger limestone belt. But so far as is known it disappears beneath the Hudson River series long before reaching the line of exploration.

Near Idlewild station, filling the space between the two branches of the Erie Railroad, there is a syncline containing the series of Siluric and Devonic strata which spreads southwestward to include Skunnemunk mountain, an outlier of Devonic strata. This is the only occurrence of these formations in this region south of the Rondout valley. The structure and stratigraphic features of this occurrence have been worked out by Hartnagel. Its northward extension in all probability terminates abruptly by a cross fault not far north of the Ontario and Western Railroad.

From these occurrences southward to the Highlands proper nearly everything to be seen through the drift is Hudson River slates.

The Highland gneisses are bounded on the north side by a fault or series of faults. This brings various members of the overlying series into contact along the margin. In the best place where a direct observation can be made the gneisses are thrust over upon the Hudson River slates along a plane that dips about 40 degrees to the northeast. It is probable that a displacement of as much as 2000 feet or more could reasonably be assumed at this place. The contact zone also is much crushed and bears every evidence of having undergone extensive disturbance of this kind. Others of this same type occur within the gneisses where weaknesses formed in this way permit the development of such notches as Pagenstechers gorge. In some cases the rock beneath the surface in these zones is more decayed and less substantial than that at the surface.

Exploration

The first borings made with the wash rig were found extremely unreliable in the Moodna valley. That is because of the very heavy bouldery drift forming the greater part of the filling on the ancient topography. Next to the Hudson river gorge itself, no

place has presented greater difficulties in penetrating this drift mantle. Boulders of such immense size occur that they have to be drilled like bed rock. In one of the holes a boulder 30 feet through was penetrated and 100 feet more of drift found below. Progress in such ground is extremely slow and costly. This is so much the more so where as in this case there are long stretches with unusually deep cover.

A glance at the accompanying profile and cross section will show a very deep and wide valley. Many of the borings are more than 300 feet in drift which almost wholly obscures the ancient topography. The present Moodna is about half as deep and occupies the extreme eastern margin of the older gorge. There is a secondary gorge on the west separated from the main channel by a sharp divide. A few other smaller notches in the line represent smaller tributary or independent stream courses. One of these of much interest is known as Pagenstechers gorge.

The rock floor at all points except two in the central Moodna valley including its two nearest tributaries is Hudson River shales, slates and sandstones of considerable variation, sometimes much brecciated. The two exceptional borings are no. 8/A44 and no. 16/A44 on the west flank of the westerly tributary gorge, and they are in pegmatite and granitic gneiss which is in all probability the narrow southerly extension of the Snake hill ridge. Here again neither quartzite nor limestone were found on the flank, a condition that seems to support the view of a double fault along the Snake hill ridge.

In striking contrast with the broad central Moodna are the two narrow and very deep notches farther to the east, the first in slates and the second (Pagenstechers) in Highlands gneiss.

Special features

Course of the Moodna. The chief interest centers around the Moodna channel. There are several unusual conditions, for example:

The rock floor along the profile is almost flat for a distance of nearly half a mile in spite of the fact that there would seem to be every reason for a different form. The differences in hardness of rock floor alone would encourage differential erosion; and, since the structure of the formations, the strike, is almost parallel to the supposed course of the stream, the influence of different beds would be at a maximum. Furthermore, the deep gorge of the Hudson, into which the stream flowed is only 2 miles away;

and if that gorge represents stream erosion to such depth (over 75 feet) it would indicate a gradient of nearly 300 feet to the mi for the last 2 miles of the Moodna — a condition to say the leas decidedly unfavorable to the development of a flat-bottomed valley

Of course, if the profile as determined can be assumed to ru exactly parallel to the old stream channel for half a mile it woul be less surprising. But even then it is too flat. For so short a dis tance from the Hudson gorge the gradient ought to be muc greater than the variation observed in the Moodna channel. Ther are certainly reasons in the structural geology favoring a northeas course instead of one parallel to the profile line. And if th stream really did flow across this structure, the differences o hardness of beds ought to have encouraged a much greater differ ence in depth of channel than the profile presents. With structures all running northeast there is every reason to expect the strean to follow them.

Recent exploratory data strongly supports the theory that the Hudson gorge at Storm King gap is widened and possibly some what overdeepened by glacial ice. Under normal stream relations one might consider the Moodna a tributary hanging valley, itself rounded and smoothed to a broad U-shape by ice. This would be a very easy solution if it were not for the fact that this tributary Moodna opens into the Hudson as a reversed stream, i. e. it opens against the flow of the Hudson and more or less directly against the known ice movement. It can not be a hanging valley therefore of the normal sort. If a hanging valley of ice origin at all it would necessarily be one therefore gouged out by ice moving from its mouth toward its head, a case that so far as the writer knows has never been observed. The chief objection to this theory is that in no other gorge or channel (with one exception, the Hudson at Storm King gap) anywhere in the region so far as known is there any evidence of serious modification of an original stream channel by the ice invasion. Of course, the axis of the valley is favorable and the situation is peculiar in that it parallels the Highlands front in this vicinity and the action of the ice may be assumed to have been somewhat concentrated along this margin because of the obstruction.

Inner notch or secondary gorge. Those who habitually emphasize ice action would no doubt choose to regard this whole valley as shown in the profile, as chiefly glacial in character and origin. If that explanation is the true one, then it must be admitted that a deeper smaller inner notch or gorge is unnecessary and indeed unlikely.

The critical point therefore in the whole argument is as to the origin of the valley, i. e. is it essentially a stream valley? Or is it as to present rock floor form wholly a glacial valley?

If it is a stream valley then no doubt full account must be taken of the proximity to the Hudson, and the possibility of developing a temporary graded condition and some adequate allowance must be made for its work during the subsequent continental elevation and the deepening of that river to several hundred feet below the known bottom of the Moodna. In short, one would expect a narrow deeper notch in the Moodna floor as a result of this rejuvenation. But on the contrary if in preglacial time the stream were not so powerful and had not been able to keep pace, and if the ice movement can be assumed to have concentrated along this line to such efficiency as to gouge out a groove 3000 feet wide almost flat to a depth of 300 feet only guided in direction by the original Moodna, then one may readily abandon the idea of a deeper notch.

One or the other of these types of origin must be the chief factor in reaching a reasonable opinion as to the presence of an inner notch.

In any attempt to choose between these factors, one is led to reconstruct the preglacial drainage lines. When this is done it at once appears as most probable that there was at that time as now a considerable area tributary to the Hudson with a stream course very much like the present Moodna. In other words a fair sized stream is assured. Once such a stream is granted and the effects of its work reckoned in full knowledge of the adjacent Hudson, and its probable behavior is studied in the light of the data obtained in exploration of the valleys of other tributaries, it becomes more and more difficult to wholly eliminate the inner gorge idea. It seems to the writer probable that the valley owes its erosion chiefly to the preglacial stream. But the channel has suffered subsequent widening and smoothing by ice especially in its upper and broader portion, below which there may yet be a notch. One must admit that the results of boring prove the notch to be very narrow, less than 150 feet, or else not there at all. In reaching an opinion as to the possibility of one so narrow, it is worth while to note that the Esopus, which is a larger stream, has cut down at Cathedral gorge to a depth of from 50 to 80 feet with almost vertical sides and only about 150 feet wide. This gorge furthermore is cut in almost horizontal strata of such character that there is no special structural tendency in them to contract the stream. At the Moodna on the contrary, in addition to the smaller

size of stream, the rocks stand on edge and run parallel to the supposed course so that this structural influence is toward a narrow and reasonably straight gorgelike form. It is not only possible that the gorge is narrow, but even probable that it is narrower than the present Moodna, i. e. less than 100 feet wide.

How deep such an inner gorge may be if it does exist is a practical question in this particular case, because its depth has a direct influence on choice of depth of pressure tunnel. Because of the evident narrowness it is likely that it is not of very great depth — in view of the quality of these shales perhaps not over a hundred feet.

Is there any one point more than another favorable for such a notch? There are two facts bearing on this question, (1) the variation in core saving which indicates that hole no. 5/A44 with 7% has a recovery of only 1/5 the average, and (2) the fact that hole no. 15/A44+, which is the next hole, shows the lowest bed rock in this valley. On the ground of profile therefore and on the ground of structural weakness there is reason to choose this space between no. 5/A44 and no. 15/A44 as the most likely position.

Summary. The very abnormal profile of the Moodna valley based upon the borings may be due either (1) to parallelism with the stream course, or (2) to a graded condition of the stream in some preglacial epoch, or (3) to modification of an original less prominent channel by ice erosion.

It is the opinion of the writer that the ancient stream crossed the profile line much as the present stream does, that the additional narrower valley immediately to the west side is that of a preglacial tributary instead of a bend of the Moodna itself, that there was a development of a moderate sized somewhat flattened valley corresponding to the benches and shelves noted in other streams, including the Hudson, that subsequent elevation of the continent rejuvenated the stream which cut a deeper narrow inner notch, that glacial ice moving in reverse direction widened and smoothed this upper portion of the valley, but that there may yet be a remnant of the deeper notch in its bottom, and that the space between holes no. 5/A44 and no. 15/A44 is the most likely location of this inner gorge.

Tributary divide. The sharp divide between the two deep portions of the valley bottom has proven an evasive feature in the later exploration. Two holes put down a short distance to the southward (24/A44 and 20/A44) failed to find the rock floor so high, one reaching rock at a depth of 181 feet and the other failing

to find rock even at 213 feet. Two others nearly a thousand feet to the westward, however, found rock again at approximately the same elevation as the divide. If this is a tributary stream divide therefore it must have an east-west trend.

Pagenstechers gorge

This is a notch between Storm King ridge and Little Round top occupied by a very small mountain stream. The rock floor is granite gneiss of the Storm King type. Its special characters are (1) extreme shattering or crushed condition, and (2) extensive decay along this zone which has softened the rock constituents to great depth.

Considering the nature of the granite gneiss in general this narrow gorge is a surprisingly deep one. But this is no doubt due to the influence of the decayed crush zone. The drill cores taken from the holes that penetrated the floor at this place are so much altered that, after several months exposure to the air, they can be readily crushed in the hand. Hole no. 16/A45 which is centrally located penetrated to —196 feet. It is in material of this same condition, to at least — 100 feet. Similar conditions are proven to the north of the line, shown in the accompanying profile and a rapid increase in depths. From the surface outcrops farther up the gulch it is easy to see that the crushed zone extends in that direction with the strongest lines about s. 70 w. This is doubtless on the strike of the fault lines of the northern border of the range. It is of more than usual interest in showing the depth to which incipient decay has penetrated in these crush zones, and the efficiency of stream erosion along them.

Overthrust fault

The principal fault line follows the margin of the granite gneisses. At the best exposure of it the Hudson River slates are overridden by the gneiss. This represents therefore the cutting out entirely of the Wappinger limestone and the Poughquag quartzite and a part of the slates by the displacement which must amount to at least 2000 feet and probably more. The same relation is indicated by the borings and by the outcrop near the village of Cornwall, but a little limestone is found midway between the two points along the strike of the fault. The strike of the fault averages about n. 65° to 70° e., but locally, at the best exposure, it is only n. 35° e. The dip is southeast at an angle of approximately 45 degrees.

Statistics

Moodna valley

1 HOLES BORED UNDER AGREEMENT NO. 18

No. A18	Surface elevation in feet	Rock elevation in feet	Rock penetration in feet	Per cent core saved	Kind of rock
1	86	+27	22	0	Slate and sandstone

(On porosity test with plug at 58 feet deep the loss of water was 6 gallon per minute with pressure of 0–10 pounds per square inch.) Test unsatis factory because of large hole.

No. A18	Surface elevation in feet	Rock elevation in feet	Rock penetration in feet	Per cent core saved	Kind of rock
2	236.5	?	0	0	0
3	136.3	36.7	26	0	Slate

(On porosity test with depth to plug 173.5 feet and pressure 0–60 pounds per square inch the loss was 5 gallons per minute.) Test unsatisfactory because of large hole.

No. A18	Surface elevation in feet	Rock elevation in feet	Rock penetration in feet	Per cent core saved	Kind of rock
4	259.6	39.4	154.5	75	Slate and sandstone
5	295.5	37.5	129.2	71	Slate and sandstone
6	302.7	?	0	0	0
7	297.0	+26	30.7	0	Slate

2 HOLES BORED UNDER AGREEMENT NO. 40

No. A40	Surface elevation in feet	Rock elevation in feet	Rock penetration in feet	Per cent core saved[1]	Kind of rock
1	276	201	125	0	Slate
2	274.3	228.8	52.5	0	"
3	294.7	257.7	45.3	0	"
4	273.1	222.1	139.7	60	Slate and sandstone
5	347.1	239.1	48.7	0	Slate
6	374.6	250.6	38.0	0	"
7	168.4	40.4	110.1	88	Slate and sandstone
8	188.7	168.2	325	76	Slate and sandstone
9	176.3	164.3	25.5	0	Slate
10	172.3	46.3	26	0	"
11	169.9	98.9	25.5	0	"
12	221.2	208.2	25.5	0	Slate and sandstone
13	226.7	210.7	32.7	0	"
14	226.6	212.6	31.0	0	"
15	230.1	215.1	32.5	0	Slate and sandstone
16	208.3	184.3	32.0	0	Slate
17	169.2	43.2	25.0	0	"

[1] In cases which show no recovery of core a method of drilling was employed different from the others and the rock was ground to pieces. Failure to recover core may therefore be no indication of poor rock quality.

3 HOLES BORED UNDER AGREEMENT NO. 44

No. A44	Surface elevation in feet	Rock elevation in feet	Rock penetration in feet	Per cent core saved	Kind of rock
1[1]	313.6	—17.4	167.5	15	Slate and sandstone
2[1]	274.5	+171.5	229.6	20	Slate and sandstone
3	282.7	+39.7	58.8	14	Slate
4	277.8	—22.2	166.7	26	Slate and sandstone
5	299.5	—47.0	50.9	7	Slate and sandstone
6	279.5	—40.3	43.0	27	Slate
7	299.2	—51.6	102.2	27	Slate
8	277.	+89.0	109.3	57.6	Granite gneiss and quartz
9	282.6	+7.6	90.	13	Slate and sandstone
10	230.5	—39.5	154.7	49	Slate and sandstone
11	249.5	—32.5	93.5	11	Slate and sandstone
12	272.0	—45.	58.6	30	Slate and sandstone
13	288.4	—37.6	79.0	13	Slate
14	185.1	—39.9	91.8	32	Slate and sandstone
15	301.8	—59.2	75.	45	Slate and sandstone
16	277.3	+25.9	104.6	43	Pegmatitic granite
17	300.	—42.	75.2	33	Slate and sandstone

[1] Porosity test made on hole no. 1 shows a loss of .03 gallons of water under 100 pounds pressure with packer at depth of 387 feet. Depth to ground water 217 feet.

Porosity test on hole 2/A44.
Ground water level at a depth of 90 feet = el. + 184.5′.

SUMMARY

Depth to packing in feet	0 / 40	20 / 60	40 / 80	60 / 100	80 / 120	100 = Gage pressure; 140 = Calculated pressure[1]
46	.25	.37	.50	.64	.79	1.03 = gallons lost
96	.20	.27	.35	.42	.52	.67 "
47	.09	.12	.16	.19	.23	.28 "

[1]Calculated pressure equals average pressure plus weight of column of water from surface to ground water level. Gage pressure is given in pounds per square inch. Loss is in gallons per minute.

4 HOLES BORED UNDER AGREEMENT NO. 45

No. A45	Surface elevation in feet	Rock elevation in feet	Rock penetration in feet	Per cent core saved	Kind of rock
1a	426.2	278.4	19.7	0	Slate with quartz
2	390.5	266.5	76.	0	Slate
3	442.8	286.8	25.5	0	"
4	432.9	268.9	31.	0	"
5	433.	307.5	36.5	0	"
6	180.1	161.8	81.7	53	Slate with quartz
7	179.4	163.4	26.0	0	Slate
8	214.2	142.2	46.5	0	Decayed granite gneiss
9	179.4	151.9	27.5	0	Slate
10	260.1	237.1	34.0	0	"
11	214.6	155.6	95.5	0	Decayed granite gneiss
12	237.6	236.6	35.5	0	Slate
13	182.7	168.6	287.4	48	"
14	269.8	257.3	28.	0	"
15	209.6	130.1	36.1	0	Decayed granite gneiss
16	213.2	11.7	308.3	28	Decayed granite gneiss and seamy gneiss
17	387.6	387.6	163.0	69	Gneiss and dyke rock

CHAPTER IX

ROCK CONDITION AT FOUNDRY BROOK[1]

Foundry brook is a small stream entering the Hudson at Cold Spring in the Highlands. It drains a rather abnormally large valley bordering Bull mountain, and Breakneck ridge on the east, and its axis is in the strike of the principal structure of the gneisses which form the chief rock formation of the floor. This valley is in exact line with the course of the Hudson from West Point immediately southward, and its rock formations are similar in character and condition.

There is greater variety of rock composition in this belt, i. e. the Foundry Brook–Hudson river belt, than in any other in the Highlands of similar area. The eastern half of the belt is a typical development of banded gneisses and schists and quartzites belonging to the sedimentary representatives of the Highlands gneiss. Small layers of interbedded limestones are frequent together with serpentine, and mica and graphite and quartz schists. In addition along the east bank of the Hudson, they are profoundly modified by crushing and shearing in zones that trend with the formation, i. e. in a direction leading toward and through Foundry brook valley.

The west side is much less variable and is bounded at the margin by one of the most massive types of the region — the Bull mountain and Breakneck mountain gneissoid granites, which are essentially the same as that of Storm King mountain.

But additional structures enter Foundry brook valley from the western side at an acute angle with its axis and formational trend. These additional structures are two well marked faults, which cross the Hudson — one along the precipitous southeast face of Crows Nest and the other along the southeast face of Storm King mountain. These are the most pronounced escarpments of the whole region. The first one crosses the Hudson between Cold Spring and Bull mountain and in passing northeastward loses much of its influence upon topography and its movement is probably dissipated in that direction. A line from the southeastern face of Crows Nest to the point to be described runs n. 50° e.

[1] Explorations at Foundry brook were done under the direction of Mr William E. Swift, division engineer, now in charge of the Hudson River division of the Northern aqueduct.

Explorations

Foundry brook therefore contains structures that could produce considerable effect upon the quality and condition of rock floor. The rock floor is covered with heavy bouldery drift — thicker on the Bull mountain flank than in the valley bottom proper. Where the aqueduct line crosses the floor is at an elevation of 200 feet to 350 feet A. T. Hydraulic grade of the aqueduct is about 400 feet.

The lowest bed rock found along the line is 182.3 feet and the channel of the present stream coincides with the preglacial one in that portion of its course. There are two secondary channels — probably tributary stream channels on the west side. One of these lies under 70–80 feet of drift.

Borings were made for the purpose of determining the rock floor profile and the condition of bed rock. In most of them the ordinary gneisses and granites were penetrated in normal condition.

But in a few a very unusual condition was found. Hole no. 2 at el. 347 feet near the west or Bull mountain margin penetrated 49 feet of drift to el. 298. Then the drill passed into gneiss which was at the top, the first 30 feet, of a fair quality. This is shown by the core recovered — the first 12 feet recovering over 50%. But the percentage of recovery rapidly fell off — amounting to only 36% in the first 50 feet. Only 1 foot of core was recovered in the next 30 feet, or only 3%. While from that point el. 220 feet to the bottom of the hole el. 51.8, at a depth of 295.7 feet from the surface, nothing but fine decomposed matter was washed up. There was no core at all. This was at first reported as sand by the drillmen, and, coming at a time when exploration of deep buried gorges was the rule at other points of the aqueduct, there were many questions about the interpretation of this new hole, the first assumption of the drillers being that an overhanging ledge of a very deep gorge had been penetrated passing through it into river sands below. A little study of the material proved that this view is untenable. The sandy wash from the drill is true disintegrated gneiss much decayed and dislodged by the drill.

But the meaning of it and the extent of it are after all important additional questions.

Interpretation and further explorations

It is certain that the soft material and the "sand" reported from this boring represent rock decay induced by underground water circulation. Water circulation is rather free as is shown by the

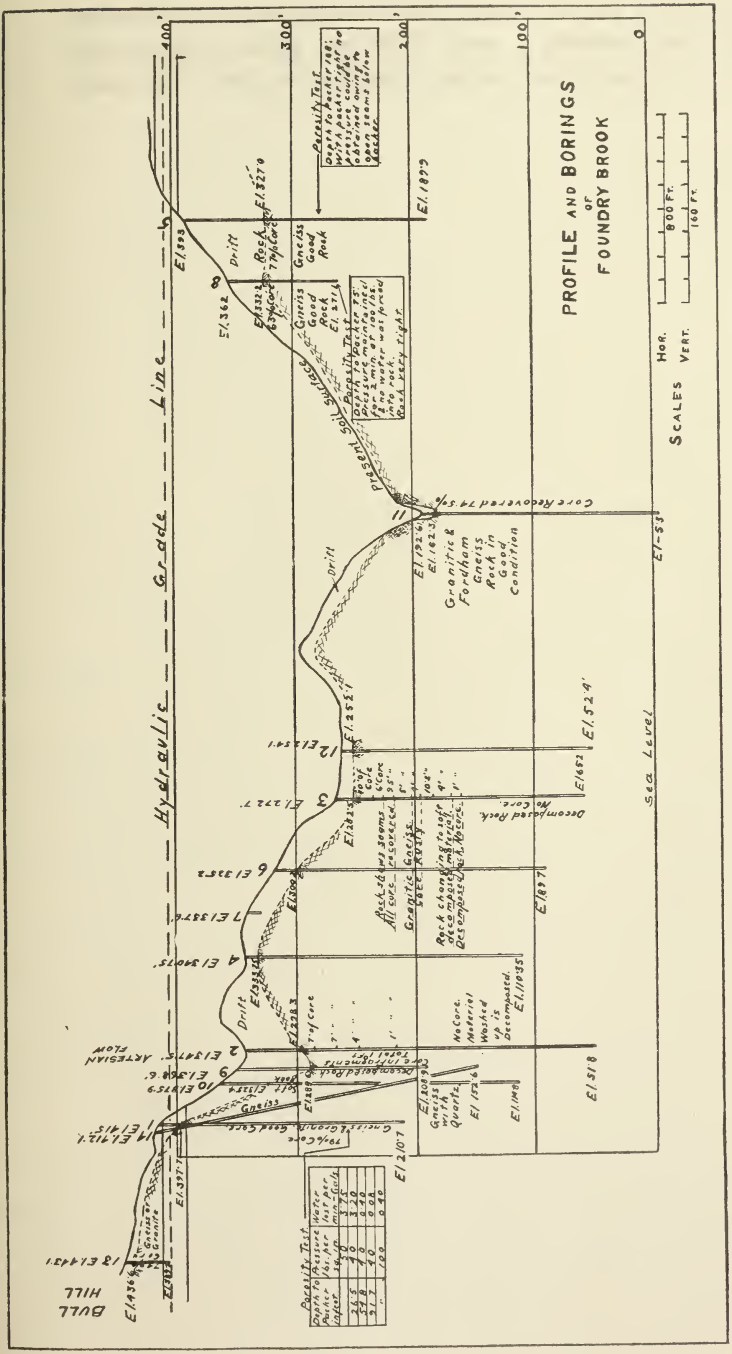


Fig. 29 Structural detail of Foundry brook valley as indicated by borings.

fact that there was an artesian flow from this hole of 10 gallons per minute after reaching a depth of 80 feet, which increased to 15 gallons per minute after reaching a depth of 253 feet. This underground supply is maintained since completion and the pressure is sufficient to raise the water about 15 feet above the surface.

This is a behavior that is consistent with the geologic conditions. The boring has no doubt penetrated a crush zone following one of the faults which enters this side of the valley. The crush zone dips steeply and the boring has penetrated the hanging wall of more solid rock in the first 50 feet and, after reaching the broken and decayed portion of the zone, has swung off parallel to the dip and avoiding the more resistant foot wall has followed down on the soft inner streak.

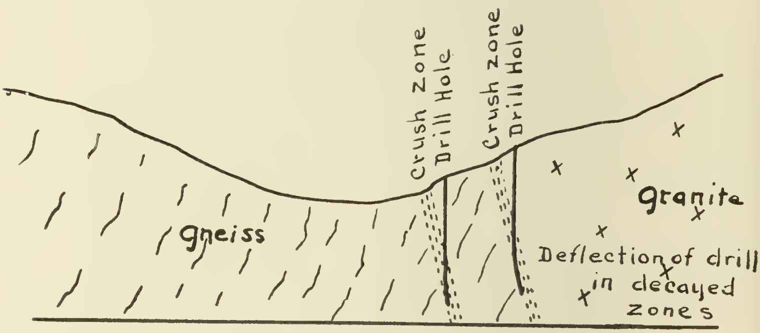


Fig. 30 Sketch illustrating the interpretation of geologic structure across Foundry brook valley indicating the relation of certain borings to them and their supposed influence in deflecting the drills

This crush zone extends on northeastward across higher ground where opportunity for taking in surface water is offered. This is without doubt the source of supply for the circulation which furnishes the artesian flow and which has been so effective in producing decay to great depth. But the circulation and associated decay are probably limited to comparatively narrow zones. There is no good reason for assuming large masses of rotten gneiss at great depth. The worst zones are narrow but may be comparatively deep, i. e. they may extend much deeper than any of the borings yet made in this valley. The depth of decay is related to the outlet for underground circulation which in this case is the gorge of the Hudson.

Several other borings encountered similar conditions, especially those on the west flank of the valley within range of the belt in which the fault seems to be located.

Hole no. 9 reached the rock floor at a depth of 80 feet, and then penetrated rock to a depth of 159.7 feet. All of the material is badly decayed. Only 1 foot of core was recovered from the whole boring and that is mostly quartz coming from a veinlet or pegmatitic streak at 141 feet. Water under slight pressure was encountered in this hole also. But because of the somewhat greater elevation of the surface at this than at hole no. 2 there is not a constant outflow.

Two other holes immediately to the west show much better rock condition — no. 1 showing 79% core recovery. Also two on the east side at greater distance [*see* accompanying profile] show good rock. But one other no. 3 at a distance of over a thousand feet to the east encountered another zone of decayed rock, the record being very similar to no. 2 in that poorer conditions are shown at depth than near the surface. Rock was found at a depth of 20.2 feet. From 20.2 to 116 feet the gneiss was quite hard, 55.3 feet of core being recovered or 57.7%. But from 116 feet to the bottom 207.5 feet the material was as bad as in hole no. 2, and no core was recovered.

Several other tests were made on the borings with a view to determining the character and extent of these features more definitely. For example, if the interpretation given for the behavior of no. 2 and no. 3 is correct it ought to be possible to survey the holes and determine a deflection from the vertical as the drill deviated from its course to follow the softest streak. A survey conducted for this purpose indicates just such a result. The accompanying sketch shows the data plotted. The drill was deflected 4° 36′ at a depth of 50 feet, 7° 36′ at 100 feet, 8° 2′ at 150 feet and 9° 40′ at 198 feet.

Pressure tests were made for porosity on some of the holes in sound rock. Some of these data are given on the profile.

Some of the rock of this valley, if very extensive, such as that in borings no. 2, no. 3 and no. 9, would be very poor ground for tunneling. The practical question involves especially the width of these zones, are they a foot wide or are they a hundred? In an attempt to help settle that question an inclined hole was proposed that was to run at an angle low enough to crosscut these belts. Accordingly hole no. 14 was bored inclined 40° 26′ to the horizontal and started on the solid granite gneiss. The results were not

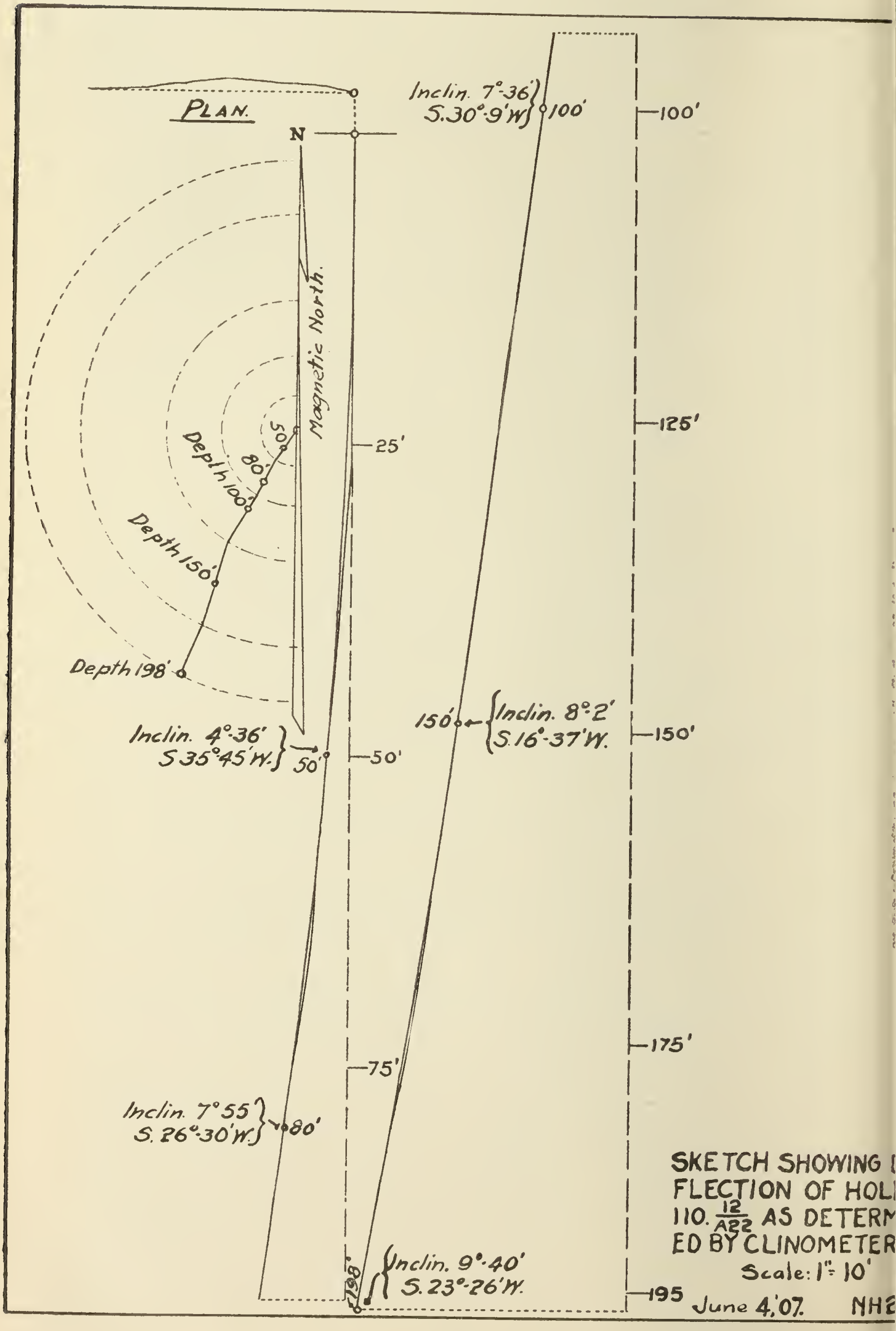

PLAN.
N
Magnetic North.
50'
80'
Depth 100'
Depth 150'
Depth 198'
25'
Inclin. 4°-36'
S 35°45' W.
50'
50'
75'
Inclin. 7°55
S. 26°-30' W.
80'
198'
Inclin. 9°-40'
S. 23°-26' W.
Inclin. 7°-36'
S. 30°-9' W
100'
100'
125'
150'
Inclin. 8°-2'
S. 16°-37' W.
150'
175'
195
SKETCH SHOWING
FLECTION OF HOL
110. 12/A22 AS DETERM
ED BY CLINOMETER
Scale: 1" = 10'
June 4, '07.
NH

Figure 31

very encouraging. The decay is shown not to be confined to mere seams. The doubt raised by so much bad ground has finally led to the adoption of a different plan for crossing Foundry brook valley and no further data are likely to be added by this work. As it now stands the borings at Foundry brook indicate the deepest decay of any yet made in granites or gneisses except those of Pagenstechers gorge on the north side of Storm King mountain. Both cases are of similar origin and history, but Foundry brook is apparently the more complex in occurrence. There are several parallel zones along which there is extensive decay to a depth of more than 300 feet.

CHAPTER X

GEOLOGY OF SPROUT BROOK

Three creeks unite to form an inlet at the sharp bend in the Hudson immediately above Peekskill. The middle one of these is known as Sprout brook. It occupies a deep and narrow valley that is well marked for 10 miles in its lower course and is traceable as a physiographic feature of less prominence to the north margin of the Highlands. Its persistence indicates some important structural control in erosion.

Geology

This valley lies in the midst of the most typical gneisses and granites of the Highlands region. And in addition several of the "iron mines" of Putnam county lie on its western flank. The rocks are complex granitic and quartzose gneisses and granites. Foliation and banding and bedding wherever this appears is parallel to the axis of the valley. The most notable geologic feature is the occurrence of a broad belt of crystalline limestone throughout the lower 4 miles. It is undoubtedly chiefly this limestone, which is less resistant to weather than the gneisses, that controls the form and size of the valley. As to geologic relations, this is one of the most interesting formations of the region. It is coarsely crystalline, full of silicious impurities at many places and carries small igneous injections and dykes, and so far as the bedding can be followed, stands almost on edge. Although an actual contact is not seen, at several places the limestone and gneiss approach within a few feet of each other and it is certain that no other formation can come between them. This is more certainly indicated in the northerly extension of the valley where the limestone gradually disappears leaving only the gneisses and granites. That there may be a fault contact must be admitted, but of this there is no good evidence in the field.

Such relations and character show that this limestone is similar to the smaller interbedded occurrences noted frequently with the gneisses in the Highlands and elsewhere. If it is of that type then it is the largest representative yet found in that series. But it is also in these characters similar to the Inwood limestone of more southerly areas. The overlying Manhattan schist which is lacking

may have been removed in erosion. One of these types it resembles, but it can not be the Wappinger (Cambro-Ordovicic) as was pointed out by the writer in a former report.[1] The Wappinger, wherever known to be such, is never intruded and always lies above a thick quartzite (Poughquag). It does so even in the next valley (Peekskill creek) less than a mile distant. With the interpretation of this Sprout Brook limestone therefore is involved the correlation and interpretation of the age of much greater areas. That the Sprout Brook limestone is not Wappinger is clear enough, but it could be either interbedded (Grenville) or Inwood. If it is Grenville then of course it has no direct bearing on the Wappinger-Inwood question and these two might be equivalents. But if the Sprout Brook limestone is not Grenville (interbedded) then it must be Inwood and in that case the Inwood and Wappinger are not equivalent — which means that there are two series above the gneisses instead of one — an Inwood-Manhattan series, and a Poughquag-Wappinger-Hudson River series. At the present time it is not possible to give with certainty a final interpretation of the Sprout Brook limestone.

Explorations[2]

It was at first believed that a pressure tunnel could be constructed advantageously at the point of crossing this valley and borings were made to test rock conditions. The data gathered in exploration are indicated on the accompanying geologic cross section [fig. 32].

Borings indicate that the rock floor has been eroded to a few feet below present sea level and that the gorge has a drift filling of more than 150 feet. The central borings penetrate limestone and indicate a total width of this type of more than 400 and less than 600 feet. The best estimate on the basis of these explorations is 500 feet. Whether this width represents one thickness of the formation as would probably be the case if it is an interbedded Grenville layer, or part of a double thickness due to infolding, as would probably be the case if it is the Inwood, there is no evidence. The thickness seems to be even greater farther south in the same valley (it becomes ¼ mile wide), but it can not be

[1] Structural and Stratigraphic Features of the Basal Gneisses of the Highlands. N. Y. State Mus. Bul. 107 (1907). p. 361–78.

[2] Explorations at Sprout brook are in charge of Mr. A. A. Sproul, division engineer in charge of the Peekskill division.

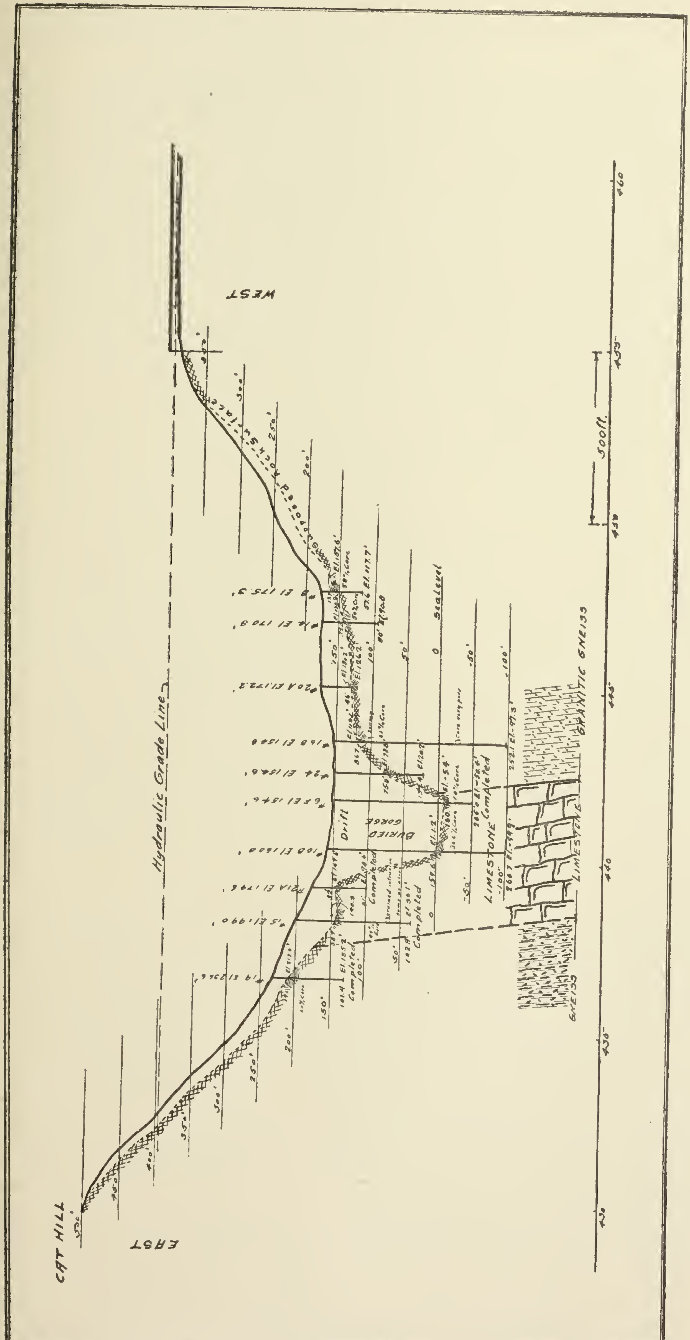


Fig. 32 Geologic cross section of Sprout brook as indicated by the exploratory borings of the Catskill aqueduct

accurately measured and there is no way of guarding against repetition of folds. The valley floor is decidedly terraced at an elevation of about 130 A.T. One side is limestone and the other is granitic rock. This is probably a local mark of the Tertiary base leveling work.

Because of the great depth of this narrow gorge, it would require a 500 foot shaft at each side to lead from hydraulic grade down to a safe level for the pressure tunnel. For a crossing not more than 2000 feet long this is excessive and the cost becomes greater than by other methods of construction. Consequently the tunnel plan has been abandoned and it is not likely that further data bearing upon these questions will be added.

CHAPTER XI

STRUCTURE OF PEEKSKILL CREEK VALLEY

Immediately east of Sprout brook, described in the previous section, is Peekskill creek, which drains the largest valley emerging from the southern margin of the Highlands. This valley as a physiographic feature is continuous with the Hudson river gorge from the sharp bend at Peekskill to Tompkins Cove. There are important structural features along the strike of this valley which extend very far beyond the limits of Peekskill creek itself, among which are strong folding and block faulting. The chief fault continues to the southwest with still greater prominence and appears on the west side of the Hudson in the escarpment forming the southeastern margin of the Highlands continuously for many miles into New Jersey.

Near the Hudson, Peekskill creek and Sprout brook unite and the structures and formations characteristic of each valley converge until in the last half mile of their united course rock formations characteristic of Sprout brook lie on one side of the valley, those characteristic of Peekskill creek on the other, and the contact which follows the divide to that point then passes beneath the waters of Peekskill inlet. Because of the block faulting which has carried down overlying formations and protected them from the total destruction characteristic of the central Highlands region this valley is of unusual interest.

Explorations [1]

The aqueduct line crosses this valley about 3 miles from the Hudson, and in determining the possibility of crossing by pressure tunnel in rock a considerable number of explorations were made. Enough has been done to outline the rock floor profile very definitely and to determine the condition of the formations.

An examination of the drill cores and records of explorations shows the following facts which are compiled as fully as possible on the accompanying cross section.

Phyllite. One boring (no. 1) is in a phyllite whose character and relation to other formations leads to the conclusion that it

[1] These explorations were directed by Mr A. A. Sproul, division engineer of the Peekskill division with headquarters at Peekskill, N. Y.

belongs to the Hudson River slate series. This type of rock forms the whole western side of the valley for several miles. Beds stand on edge or dip steeply southeastward and are in good sound physical condition. The rock is everywhere a fine grained micaceous slate or phyllite and in some places carries pyrite crystals. It is impossible to estimate the thickness or minor structural habits. But it is clear that it forms the upper member of a series that has a synclinal structure and therefore the belt represented by the phyllite marks the axis of the syncline although the chief valley development lies wholly to one side.

Limestone. Eleven borings (no. 2, 3 D, 4 C, 11, 13 C, 18, 22, 23, 25, 26 and 29) are in limestone. All show essentially a very fine grained close textured crystalline gray or white or bluish rock with strong bedding standing nearly vertical or at very high angles. This, because of its character and relation to other formations, is regarded as the Wappinger limestone — a formation well known north of the Highlands, where it is at least 1000 feet thick. From present explorations it is now certain that a belt 3250 feet wide is underlain continuously by this formation standing nearly on edge. Unless repeated of course this would represent approximately the thickness for Peekskill valley. But it is not believed to be so thick. It is more likely that there is a threefold occurrence brought about by close isoclinal folding (a closed s-fold) as seen in the accompanying cross section. This view is supported by at least one occurrence of the underlying quartzite member near the center of the valley at a point a couple of miles farther north On the line of exploration, however, none of the borings penetrate any other formation beneath. Attention is called to additional structural details and physical conditions in a later paragraph.

Quartzite. One boring (no. 5) is in a quartzite. It is very pure, fine grained, closely bound and typical quartzite. The beds stand almost vertical and the whole thickness is known from nearby outcrops to be approximately 600 feet. From its character and relations to other formations it is regarded as the Poughquag — a well known formation of the north side of the Highlands.

Gneisses. Five borings (no. 7 E, 9 B, 17, 27 and 28) are in gneisses. These are to a considerable extent simple granite gneisses of igneous origin. But there is the usual variety characteristic of the Highlands gneisses and no doubt they are representatives of the great basal gneiss series that is elsewhere referred to as the equivalent of the Fordham of New York city.

2 Stratigraphy

This is therefore the rock series of Peekskill creek. It is the only locality on the south side of the Highlands where all are represented in complete and simple form. There is no doubt that it is the Poughquag-Wappinger-Hudson River series, in spite of the complete absence of organic evidence. A similar though not so complete and clear occurrence is to be found on the west side of the Hudson near Stony Point and Tompkins Cove. That is a part of the same structural syncline. It is probable also that the phyllite so finely developed in the village of Peekskill in the next small valley to the east is the same. But outside of these occurrences there are none that clearly represent this same series as a whole and in the same condition.

No more striking example of this fact can be found than the adjacent Sprout brook described in an earlier section. There coarse crystalline and injected and impure limestone occurs alone — no phyllite and no quartzite. When one remembers that the two occurrences so strongly contrasted, Sprout brook and Peekskill creek, converge until they actually unite, and still preserve their stratigraphic dissimilarity, without any adequate structural reason for it, the only conclusion possible is that the two occurrences represent two entirely different series of formations.

The Peekskill valley series is Cambro–Ordovicic in age; what is the other? It is older, at least that is certain. But is it (the Sprout Brook limestone) as old as the oldest of the gneisses themselves and therefore interbedded with them representing locally the Grenville; or is it intermediate — Postgrenville and Precambric — with which possibly other occurrences of rocks of similar habit and equally uncertain relations belong?

It is on the general similarity of this occurrence to the Inwood limestone as known throughout Westchester county and New York city that a tentative intermediate series has been recognized. This is the Inwood-Manhattan series. Whether it is in reality a separate older series is not regarded as proven. But for engineering and practical purposes the distinction is a good one and eminently serviceable. Further discussion may better be continued in a different publication.

3 Rock surface

The bed rock surface is pretty well outlined by the borings. A profile based upon them seems to leave no unexplored space of sufficient extent to admit a gorge of great consequence to a lower level

than is already shown in holes no. 1 and no. 11 [*see* profile and cross section, fig. 33]. The elevation indicated by no. 3 D is believed to be misleading because of the use of a drill that was capable of destroying a part of the ledge rock that would usually core. The points believed to be weakened by structural disturbance and therefore most likely to be attended by erosion and stream action are in the vicinity of hole no. 11, near the present creek, and hole no. 25, near Peekskill Hollow road.

4 Buried channels

From the accompanying cross section it will be seen that the drift cover is more than 100 feet thick over large portions of Peekskill valley. The rock floor in the middle of the valley averages approximately 25 feet A.T., while the drift surface except where cut out by stream erosion is at about 125 feet. In the rock floor there are two depressions, the large one wholly within the limestone belt and the smaller following the limestone-phyllite contact. There is not much difference in their depth so far as explored, but there is a possibility of a somewhat deeper notch in each one. The depth to which some of the limestone beds are decayed by underground circulation would lead to the belief that a deeper notch may exist.

The drift cover is chiefly partially assorted sands and gravels in the central portion of the valley, and more of a till on the eastern valley side. It is noteworthy that the present Peekskill creek lies far to one side following closely the phyllite wall.

5 Underground water

Present elevation above sea level is so slight that there is apparently little encouragement of deep underground circulation. But at certain points the rock has been found to be very badly decayed to a great depth — to at least 200 feet below sea level. This is believed to have been accomplished chiefly at a time when the region stood at a higher level. Hole no. 22 is especially notable in this connection. A comparison of the figures of core saving is one of the best lines of evidence on this question. Wherever data are at hand the percentages of saving have been put on the cross section. Hole no. 29, for example, shows a saving of only 11% in the lower 250 feet, reaching a depth of 297 feet below sea level.

The present water table profile is shown on the cross section. A great body of water stands in the assorted sands directly upon bed

rock forming essentially a great reservoir of supply that has ready access to the almost vertical limestone beds. This will give a maximum water supply to holes that penetrate porous or broken portions of bed rock. The attitude of all strata is especially favorable for admitting an almost inexhaustible supply from a considerable drift-covered area within which circulation is probably very rapid.

6 Condition of rock

All strata of this valley stand so nearly on edge that drills actually explore a very limited portion of the whole series of beds. No very great advantage is gained by excessively deep boring because the drill follows necessarily almost the same bed from top to bottom. At best only the immediately adjacent beds are penetrated. This means that much of the total thickness of beds is untouched by present explorations, and must be interpreted on the basis of their general likeness to those more fully determined. The usual succession of beds is known to be quite uniform in quality and locations where they can be studied and there is no reason to expect greater variation here.

Deviations from such normal or uniform conditions are mostly due (*a*) to local development of mica from recrystallization of impurities in the limestone, and (*b*) to crush zones developed in the process of folding and faulting which has broken the rock or weakened it enough to permit a more ready circulation of underground water. Wherever either of these structural conditions prevail, the rock has been excessively decayed, or disintegrated, or sufficiently weakened in its binding matter or its sutures to crumble in the hand or break down to a sand under ordinary boring manipulation. This condition is known to reach to –297 feet. How much deeper is not known. Probably the decay dates back in large part to preglacial continental elevation at which time probably there was more ready deep circulation with possible outlet in the Hudson gorge. This action has been all the more effective by reason of the attitude of the beds. They stand so nearly on edge that they present all their weaknesses of bedding and sedimentation structures to the destructive surface agents. They admit surface water readily and favor abundant underground circulation.

Considerable faulting occurs. The contact between the granite-gneiss and quartzite is a fault contact. Wherever seen this is sound. But a crush zone in limestone lies nearly central in the valley, cut by holes no. 23 and no. 25, where the rock shows a finely brecciated

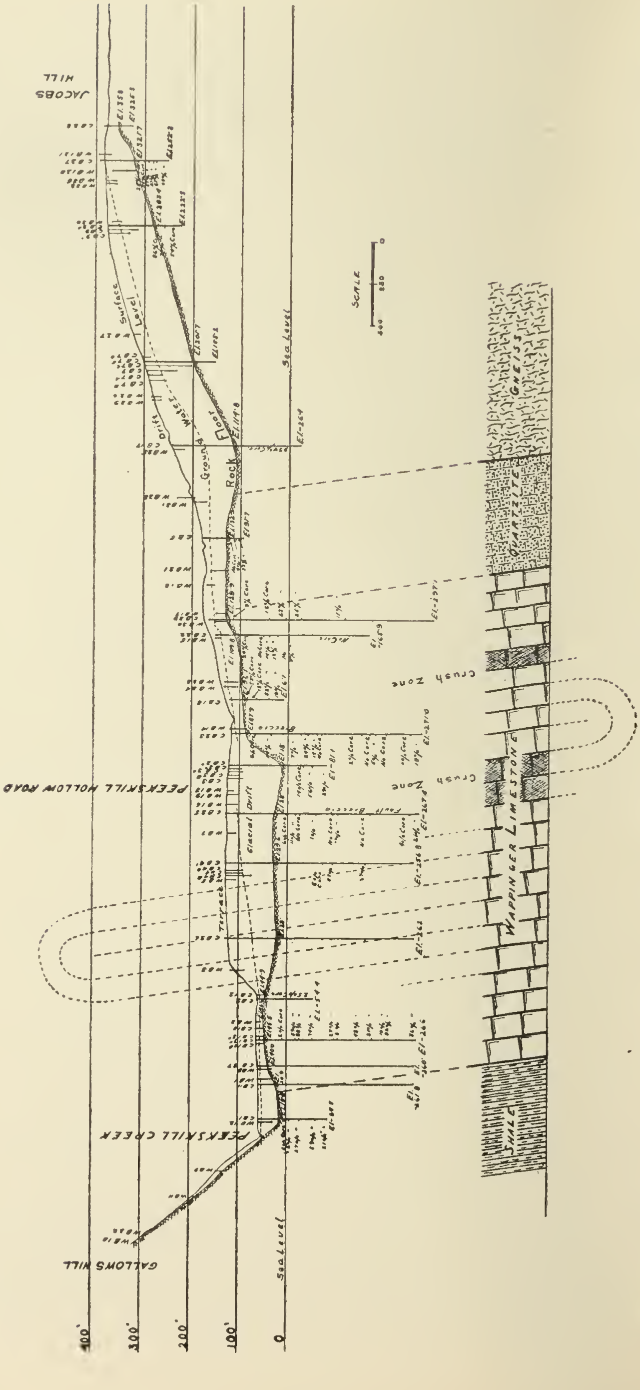


Fig. 33 Geologic cross section and detail of borings across Peekskill valley along the line of the Catskill aqueduct

condition some portions of the drill cores being literally crushed to bits.

In one hole, no. 11, near the phyllite-limestone contact, a soft, sandy condition was encountered at a depth of 133 feet, permitting the drill rods to be pushed down without boring at all, 60 feet ahead of the casing. This, however, is not believed to indicate any very extensive weakness. It is probably connected with the bedding planes or joints rather than with general decay or faulting. Four or five inches of solution and disintegration along bedding planes would account for all that has been proven. The fact that the rods could be shoved down 60 feet while the corresponding outer casing could be shoved down only half as far seems to support this view.

Summary

If a tunnel were made across this valley there would be approximately 1100 feet of it in Hudson River slate (phyllite), 3250 feet in Wappinger limestone, 600 feet in Poughquag quartzite, and the rest in the gneisses.

Some weak rock is certain to be found, especially in the vicinity of station 367+50 and 345+00 to 350+00. At both places increased water inflow would be encountered with almost exhaustless supply from the sands that lie on the rock floor above.

At about this stage in the exploration the Board of Water Supply decided to abandon the rock tunnel plan. The conditions found were considered by them too questionable. Steel pipe construction is to be substituted. As a result it is not likely that much more detail will be added to the structure of this very complex valley.

CHAPTER XII

CROTON LAKE CROSSING

It is proposed to finish Ashokan reservoir and the Northern aqueduct first. This so called Northern aqueduct reaches from the Catskills to Croton lake. Croton lake is the present supply of New York city and is already connected by two aqueducts with the city distribution. As a first step, therefore, and as an emergency measure the Catskill water will be delivered to the Croton system by finishing the Northern aqueduct first. As rapidly, however, as the whole project can be carried out the so called Southern aqueduct will be constructed to continue the Catskill water independently of the Croton supply to the city.

The Southern aqueduct department has charge of the line from Hunters brook on the north side of Croton lake to Hill View reservoir near the New York city boundary. During exploratory work it has been under the direction of Major Merritt H. Smith, department engineer, with headquarters at White Plains. Construction now going on is in charge of Mr F. E. Winsor, department engineer.

The first link in this southerly extension is to be a tunnel beneath Croton lake through which the Catskill water may pass in the same manner as it crosses other valleys. This crossing has been located a short distance below the old dam on the Croton, about 5 miles up stream from the Hudson.

The problems involved at this point include (1) a determination of the kinds and quality of rock to be penetrated, (2) their water-carrying capacity, and (3) opinion as to the proper depth for a successful tunnel.

Geological features

The Croton valley is one of the very few in southeastern New York that actually crosses the geological formations and major structural features instead of following parallel to them. In its lower portion it passes from gneiss to limestone and to schist several times. The reason for this somewhat abnormal course is probably the development of weak zones by fault movements in this transverse direction.

Only one of the well known formations of rock is exposed in the immediate vicinity of the tunnel site. This is the *Manhattan schist,* the uppermost formation of the region south of the Highlands. Along the Croton it varies greatly, the chief type being a

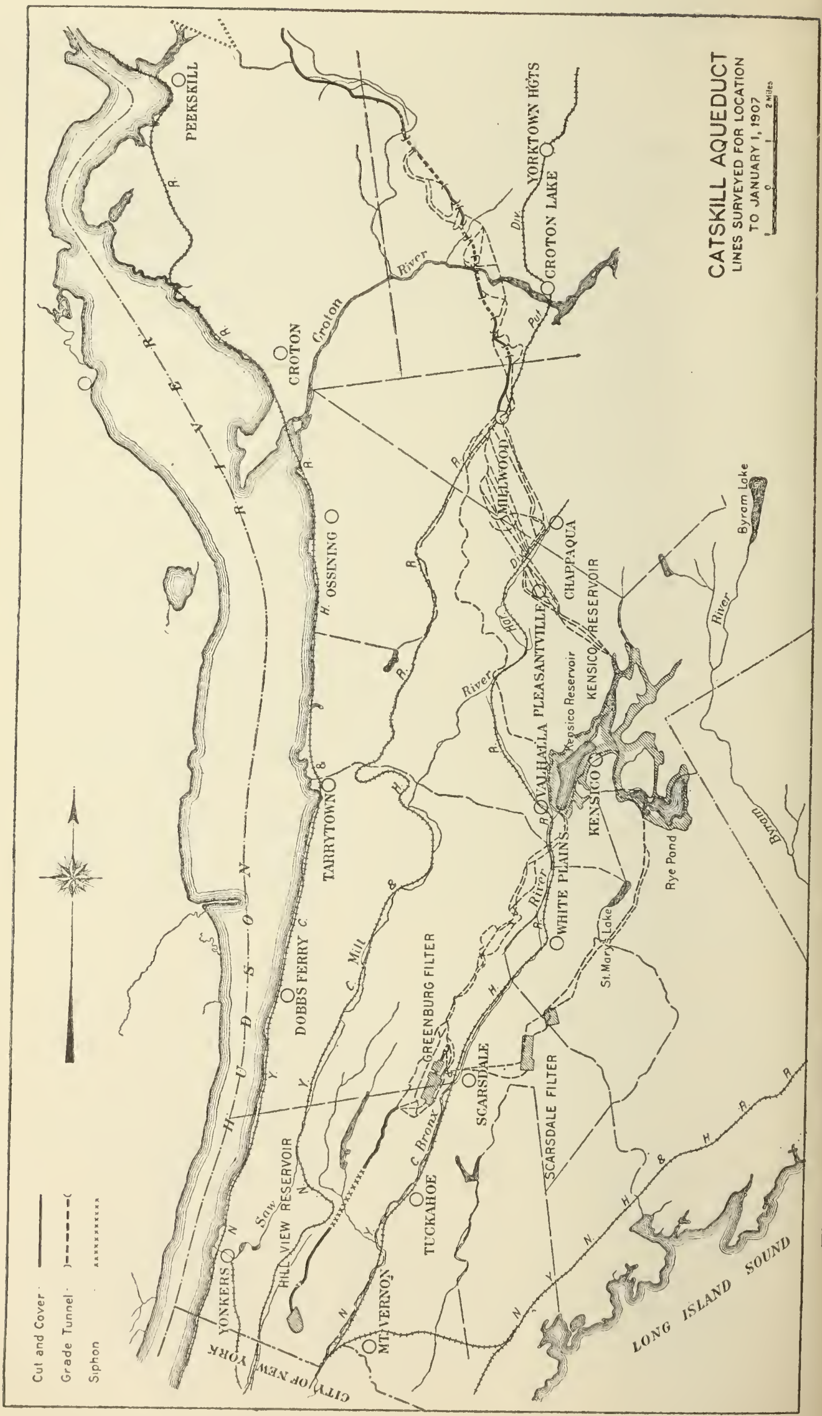


Fig. 34 General location map of the Southern aqueduct and associated parts of the Catskill supply

garnet-bearing quartz-mica schist varying from rather fine grain and semigranular appearance to a very coarse and strongly foliated structure. This part of the formation undoubtedly represents recrystallized or metamorphosed sediments. But associated with this facies there is a more dense black hornblende schist that, not only here but at many other places, is thought to represent igneous intrusions that have been metamorphosed together with sediments of various types, until both have lost almost all of their original characters. The hornblendic schist type is not so extensive as the other, the mica schist, but it is more compact and here as usual is in the better condition.

Pegmatite stringers occur abundantly, especially in the mica schist varieties. They are of no great consequence, however, as a factor in this study. They originated in the aqueo-igneous activity involved in the recrystallization of the rock when it was worked over into a schist.

Beneath this Manhattan schist formation lies the *Inwood limestone,* a bed probably at least 700 feet thick. But at this point how deep it lies and at what depth it would be penetrated nobody can tell. None of the drills have touched it. Beneath the limestone in turn lies the granitic and banded gneisses belonging to the *Fordham gneiss series,* the lowest and oldest of the region.

Along the Croton river nothing but Manhattan schist is to be seen at the surface for more than a mile above and below the proposed crossing. The same thing is true for an equal distance on opposite sides from the river at this locality.

But the structure is folded and the normal northeast-southwest trend of the folds crosses the river, every arch or anticline tending to bring the limestone and gneiss nearer to the surface. One of these folds does expose the limestone and gneiss in a strip extending from the Hudson river northeastward for two thirds of the distance to the old Croton dam. But before reaching the Croton valley this fold pitches down toward the northeast beneath the Manhattan schist and passes under the present lake (or reservoir) in that relation, not reaching the surface again for a distance of about 6 miles. At least one more fold is known to behave in a similar manner as it reaches the Croton.

These facts make it certain that there is limestone beneath the schist in the vicinity of the crossing, and that it comes nearer to the surface in that vicinity than at some other places.

South of the Croton there are several small cross faults run-

ning nearly east and west. It is believed that similar movements have affected the rock in the Croton valley itself, modifying its condition so much as to control the course of the stream. The only immediate bearing upon the problem of the Croton crossing is the question that it raises about the quality of rock and the necessity that is introduced of trying to determine whether or not there is shattering enough to be very objectionable.

Explorations and data

Six drill holes have been made on this proposed Croton lake crossing — one on either side just at the margin and four others within the intermediate space of 1400 feet. These inner four have been made from rafts floated on the lake and have penetrated water, drift cover, and rock [*see* accompanying profile and cross section, pl. 27].

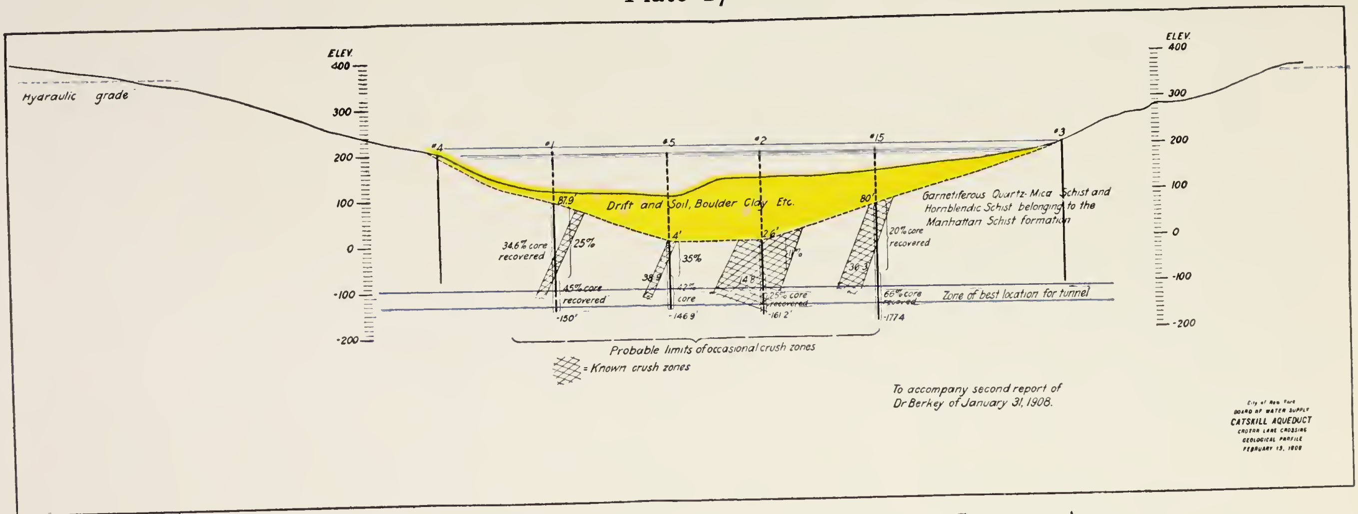
Rock floor. The depth of the preglacial Croton valley is pretty accurately determined at 0 feet or sea level. There is no reason to expect a gorge or inner channel of any consequence.

The drills have penetrated only one formation, i. e. Manhattan schist. These test holes are believed to be near enough together to eliminate the possibility of any other formation appearing at tunnel grade.

Rock condition. The two varieties of schist (1) the coarse garnetiferous quartz-mica rock, which is a metamorphosed former sediment, and (2) the darker, close grained hornblendic rock that is believed to represent an igneous intrusion, both occur in the cores brought up by the drill. Either under normal conditions is a good rock. But there are considerable differences in the physical condition of the rock. Holes no. 3 and no. 4 at the two extremes, on the lake borders, show sound rock that comes up in large cores with very high percentage recovery. This is confidently believed to represent the average condition of the rock in this vicinity at the sides of the valley.

The central holes, however, nos. 1, 2, 5 and 15, all show more broken ground. Of these holes no. 2 is much the most broken, the core recovery being only 14.8%. The pieces are small and many are smoothed (slickensided) by movement. The hole penetrates a typical crush zone resulting from slight faulting movements, and the low saving is due to the fact that the incipient fractures are not well bound together (rehealed) by later mineral change. They are probably connected with the latest movements of this kind.

Plate 27



Cross Section of the Croton Valley at the Crossing of the Catskill Aqueduct.

The tunnel is to pass beneath Croton lake, the present water supply of New York, and carry the Catskill water under pressure to the south side where it will rise to grade again. The rock is all Manhattan schist of both mica and hornblende varieties. The study covers chiefly depth of drift cover, position and extent of crushed rock, probable water circulation, and depth for suitable rock condition.

The commonest secondary mineral now filling these crevices is chlorite, and, although it may completely fill the crevices it has little binding strength. Any new disturbance or strain readily causes separation along the same original lines. But in spite of the fact that the core is broken into small pieces and shows so low percentage of recovery it is quite certain that the rock itself is not badly decayed. An examination of one of the most doubtful looking cores from the lower part of hole no. 1 showed under the microscope little evidence of serious decay. This is believed to mean that underground water circulation is not as abundant as the fractured condition of the rock would lead one to expect. Furthermore, an examination of the cores in greater detail shows beyond question that much of the fracturing is entirely fresh and must have been done by the drill itself. It is certain that the low percentage of recovery is in part due to this cause. The small diameter of the intermediate holes is contributory to the same results. Some allowance must also be made for the difficulty of working a machine from a raft on the lake.

Comparison of the cores shows a decidedly higher percentage of core recovery, and presumably therefore of rock solidity in all of the other three holes — no. 1, no. 5 and no. 15.

Hole	no. 2 —	core recovered	14.8%
"	no. 1 —	"	34.6%
"	no. 15 —	"	36.3%
"	no. 5 —	"	38.9%

It therefore appears that the last three penetrate rock that is more than twice as good in its capacity to stand drilling disturbance.

A comparison of quality at different depths is believed to be still more encouraging. The upper portions of all holes have poor recovery and comparatively poor looking rock. But in depth there is a marked improvement.

In view of the fact that the tunnel will undoubtedly be located somewhere below the –75-foot level, it is really only this lower section that is of vital importance to the project. A tabulation and comparison of core recovery from these lower portions is given below.

		1 From total depth of hole	2 From depth –75′ to bottom
Hole	no. 2 —	= 14.8% core recovery	25% core recovery
"	no. 1 —	= 34.6% "	45% "
"	no. 15 —	= 36.3% "	66% "
"	no. 5 —	= 38.9% "	42% "

Under the conditions of work, this is a fair saving and indicates much more substantial rock below the –75′ level. There are many pieces 10–12 inches in length and for a 1 inch core this may be considered very good.

It is clear, however, from a detailed inspection of the cores, that there is considerable variation somewhat independent of depth. There are occasional stretches of poorer ground in the midst of comparatively sound rock. This is believed to indicate that the crushed condition is confined chiefly to certain zones, and that these zones dip across the formation and across the holes at an angle. They are probably distributed promiscuously throughout the central portion of the valley, but are certainly more abundant and more strongly marked in the vicinity of hole no. 2 than at any other point tested. The rock profile shows that hole no. 2 has also the lowest bed rock. This is a further support to the general explanation of the valley as given above.

The chief elements of uncertainty remaining after the borings have been completed are:

1 The exact extent or widths of the chief crush zones

2 Their dip and strike

3 The possibility of others not yet touched

4 The permeability of the rock for underground water

5 The supporting strength of such rock in a tunnel of large dimensions

In spite of the uncertainties enumerated, the conditions are entirely understandable. There is little probability of finding a worse condition than that shown in hole no. 2. The permeability or porosity of these zones is of course unknown. The chief reason for believing that underground circulation is not abnormally heavy is the observation that the joints are well filled with chlorite and that other decay is not at all prominent at the lower levels. Furthermore, the rock is a crystalline type of rather successful resistance to ordinary solution agencies and therefore may be depended upon to hold its own in its present condition indefinitely. But because of the poor binding effect of the chlorite it is to be expected that blocks will fall from the roof of any tunnel where it passes through a crush zone. Timbering will be required for protection in places, but the ground will not cave or run. These zones may be expected throughout a total distance of about 700 feet — i. e. the space between no. 1 and no. 15. The chief belt of such ground probably lies between holes no. 2 and no. 5.

Summary

The lowest bed rock is about sea level.

This pressure tunnel will cut only Manhattan schist.

All rock is good ground for such work, except in certain narrow zones where it is crushed.

The extent of such broken ground is not closely delimited, but occurs at intervals for a distance of 700 feet.

The amount of underground circulation is judged to be moderate at –100 feet.

The tunnel should be located deep enough to take advantage of the improved rock conditions shown at about –100 feet. There seems to be no marked improvement below –100 feet as deep as the drills have gone.

CHAPTER XIII

GEOLOGY OF THE KENSICO DAM SITE

Kensico reservoir at Valhalla, 2 miles north of White Plains, is one of the links in the Bronx river aqueduct. It is to be greatly enlarged and made a very important storage reservoir for the new Catskill system. In line with this plan a new dam is to be built near the old site that will rise 100 feet higher than the present structure.

Extensive investigations[1] have been made to determine the character of rock floor for this massive dam. Sites both above and below the present one have been studied with the question of safety and efficiency and permanence as well as that of economy of construction in view. Involved with this is also the source of suitable stone for its construction.

Geological surroundings

Glacial drift covers the rock floor of this and neighboring valleys to a depth of 10 to 20 feet. No rock is exposed in the valley bottom at the Kensico site, but at the extremities of the proposed dam the rock floor comes to the surface in small outcrops. The material constituting the drift cover is essentially a loose, somewhat porous till passing into modified types, especially gravels and sands immediately south of the ground tested.

The character of bed rock at the two extremities and beyond the limits of the dam is easily seen from the outcrops to be Fordham gneiss on the east and Manhattan schist on the west. Between, although nothing can be seen, Inwood limestone is found by the borings as was to be expected. No other formations occur, although the Yonkers gneiss, an intrusive in the Fordham at a little greater distance figures prominently in studies of material.

The formations are in normal order and are of the usual petrographic character. All dip westward at angles that vary from 45 to 65 degrees and have a general strike a little east of north. It is evident that the whole series represents an eroded limb of a simple fold.

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[1] These explorations have been in direct charge of Mr Wilson Fitch Smith, division engineer, whose headquarters for the Kensico division is at Valhalla, N. Y. Preparations for construction have already been begun.

The Inwood limestone occupies about 800 feet of the bottom and eastern margin of the valley, lapping well up on the Fordham gneiss. The drill cores from this formation are unusually sound.

The Manhattan schist shows much broken material. There are many crush zones. This condition increases still farther west along the railway near Valhalla station.

The Fordham gneiss appears to be sound where it can be seen at the surface.

Results of exploration. Many borings have been made. They prove the general structure and succession of formations, making the boundaries definite. They increase the evidences of a rather wide prevalence of weak zones — some of them in the gneisses. And they also indicate a more extensive surface decay than was formerly believed to prevail.

The chief problems from the geologic standpoint are connected with the following features:

1 Extent of surface disintegration

2 Extent and distribution of weak zones

3 Depth of decay and perviousness of rock

Surface disintegration. Several borings on ground underlain by Fordham gneiss penetrated material beneath the drift and above bed rock that was interpreted as residuary matter from rock decay. All of this material is of local origin. Later exploration in the form of a deep trench to bed rock has proven that there is an extensive residuary mantle of this sort at the eastern side of the valley below the present dam. In places as much as 30 feet exists. Undoubtedly this material is a remnant of preglacial soil mantle that was in some way protected from removal by the ice. Few places are to be seen in all southeastern New York where there is so much left in place. In most of it the gneissic structure is still preserved, but the decay is so complete that it can be cut and handled like an impure clay.

Weak zones. It has been proven that there are weak zones in the gneisses as well as in the other rock formations. In some places the rock is so poor that no core is recovered for distances of 5 to 10 feet, and in one hole a seam of this kind 20 feet wide appears. In every case, however, the drill passes through the rotten material into the opposite wall — indicating a zone of considerable dip instead of vertical position. This favors the theory that the weaknesses follow the bedding largely and are perhaps due to

difference in the mineral make-up of the beds fully as much as to dynamic disturbances. The walls are generally good. The fragments of core are not much slickensided. In the schist this is probably not as generally true. There are much plainer evidences of crushing movements in the schist. It is a locality where one of the folds, one well developed farther south, is pinched out and there is rather general crushing of the weaker strata.

Depth of decay and perviousness. As deep as borings have gone there is occasional decay and broken material and streaks that are pervious.

Final location. The condition of bed rock, together with other considerations led finally to the selection of a site above the present dam. In general the same features characterize this site. But the rock condition is somewhat improved. On the whole the new situation is a safer one.

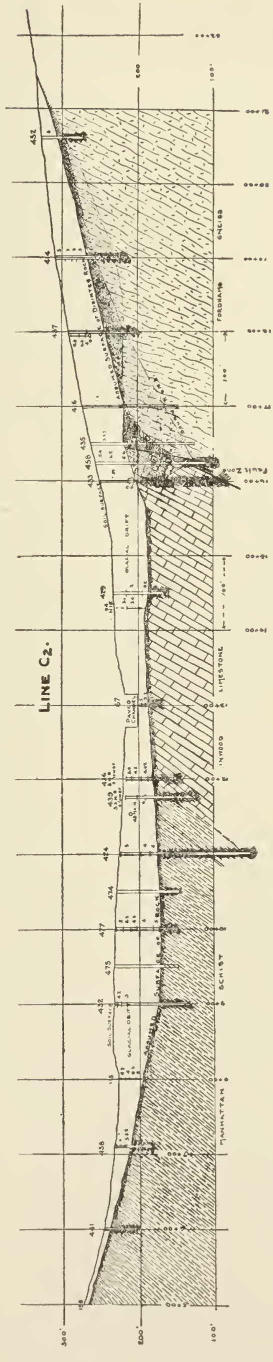


Fig. 35 Geologic cross section across Bronx valley at Vallhalla as indicated by borings on line C2 a short distance below the present Kensico dam

CHAPTER XIV

STONE OF THE KENSICO QUARRIES

The following quarries in the immediate vicinity of Kensico reservoir have been studied in the field:

(1) "Smith quarry," which is less than a thousand feet east of the southern end of the present reservoir; (2) "City quarry," which is on the immediate eastern margin of the reservoir on the east side; (3) "Garden quarry," which is a new location about 500 feet from the eastern margin about midway; (4) "Outlet quarry," 1500 feet east of the northern extremity of the present reservoir; (5) "Ferris quarries" 1000 feet and (6) "Dinnan quarry" 3000 feet farther north.

In addition to the field observations a detailed microscopic study was made on specimens of the rock taken from the Garden, Ferris and Dinnan quarries.

The question at issue is the choice of a rock for the facing and finish of the new Kensico dam. In view of the use to be made of the rock, extreme strength is of only secondary importance. But the questions of abundance, distribution, durability, purity, agreeable appearance and working quality are vital.

Types of rocks

All of the quarries occur in the broad belt of Precambric gneisses that forms the eastern margin of the reservoir extending northward and southward for many miles. The formation as a whole is very complex. But the basis of it is a black and white banded rock chiefly a metamorphosed sediment, known as the Fordham gneiss in southeastern New York. In it are intrusions of igneous rocks of many varieties and most complicated structure — dykes, bosses, veinlets, stringers etc., sometimes in such abundance as to wholly obscure the original type. The most abundant of these are, (*a*) a rather light colored quite acid rock that is essentially a granite in composition, but has a sufficiently foliate structure to be classed as a gneiss and is the same as the "Yonkers gneiss" occurring farther south, and (*b*) a dark rock containing much hornblende and biotite which is in some cases essentially a diorite in composition, but has a marked tendency to schistose structure. The former (*a*) may be called a granite gneiss and the more massive representatives of the latter (*b*) may be classed as a dioritic gneiss. In both cases at

times the blending with the original metamorphosed Fordham gneiss is so intimate that absolutely sharp limits can not be drawn. And this last condition may well be designated as a third case (*c*).

The quarries visited represent all three of these cases. Dinnan, Ferris and Outlet quarries represent essentially the "Yonkers gneiss" type (*a*) of granite gneiss. Garden quarry represents chiefly (*b*) the dioritic type of gneiss. City and Smith quarries represent the last case (*c*), or the mixed and variable type.

Field character

City quarry. In accord with the above differences in type it is found that large quantities of uniform material for such purpose as is proposed can not be obtained from City quarry. The rock there is badly jointed and is variable to a marked degree. It was not thought promising enough to test in detail.

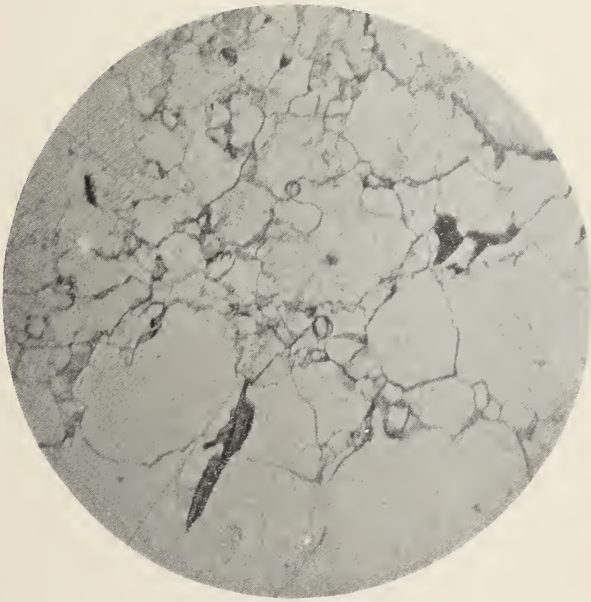
Smith quarry. The conditions of Smith quarry are better but there are similar objections. The amount of uniform material is greater. It would no doubt furnish an abundance of material suitable for use in the construction of the dam interior, but is not at this point as good a source of facing stone as some of the others to be considered.

Outlet quarry. Although this rock is characteristic Yonkers gneiss, it has at this place suffered by weathering a peculiar discoloration to such extent as to make it objectionable, both from the standpoint of appearance and perhaps of durability.

Garden quarry. There is an abundance of stone at the Garden quarry. It is fairly uniform. It is no doubt good enough from every standpoint of durability. It is well located. It can be quarried readily. But it has a very dark color and is undoubtedly less attractive than a light stone for this purpose. There are no objectionable structures, except where the strong schistose character is developed, and these could be avoided so that with a little selection a fairly uniform stone could be secured.

Dinnan quarry. This rock is typical "Yonkers gneiss." There is sufficiently large quantity. It is of good quality. It is situated a little over 2 miles from the proposed dam, but is of easy access. The jointing and other structures do not seem to be objectionable. It will work somewhat more easily than a true granite because of the gneissic structure and it has a good medium light color. The discolorations do not seem to penetrate deep and the rock shows only slight decay.

Plate 28



Photomicrograph of Yonkers gneiss from "Outlet quarry" taken in plain light to show prominence of sutures between the grains indicating the beginning stage of disintegration. Magnified about 30 diameters

Ferris quarries. The "Old Ferris quarry — is "Yonkers gneiss" considerably more weathered than the Dinnan. It is considered less promising than the "New Ferries" quarry which has been explored by the engineers of the Kensico division. The rock of this quarry site is not all of one quality. There are essentially three varietal facies of the Yonkers gneiss type and relationship. One (*a*) is essentially a granite. It has a coarse grain and shows almost no foliate structure. It has a decidedly massive appearance; but it is not of very great extent. This rock is evidently very closely related to the true Yonkers gneiss into which it passes on all sides through an intermediate variety.

This intermediate variety (*b*) has medium size of grain, is only slightly foliated and passes without sharp limitations on the one side into the granite facies and on the other to true normal Yonkers gneiss. It is not so strikingly massive as the granite, but is more [illegible] than the gneiss proper. This rock may be called a gneissoid granite to distinguish it from the other.

The true Yonkers (*c*) gneiss surrounds these two special varieties. It is of finer grain than either of the others and is more strongly foliate and is strictly a granite gneiss. Varieties (*a*) and (*b*) occur as sort of a lens within the Yonkers gneiss.

The extent of the granite as now uncovered at the site is believed to represent its limits. The prospect of enlarging the area will not meet with much success. It is essentially a local development connected with the differentiation of the parent magma from which all three varieties were derived. It seems to have been the last of the three to solidify, and it has some of the characteristics of certain pegmatite lenses.

Although this is certainly an attractive rock and one against which there is little ground for objection, it is reasonably certain that a sufficient quantity of this variety can not be obtained here for the whole proposed use. And the prospects are not good for locating another quarry of the same quality.

The gneissoid granite (*b*) is of greater extent, in fact it will be found to encroach on the present area of the granite. It is as good rock and almost as attractive as the granite.

The regular type of Yonkers gneiss such as that represented in the Dinnan quarry can be obtained in almost unlimited quantity, and, with the splendid showing that it makes in further examination, it has come to be considered the best suited to the purposes of dam construction at Kensico.

Petrographic character of the rocks

This line of investigation is confined to four sets of samples.

No. 1 The granite of the New Ferris quarry
" 2 The gneissoid granite of the same quarry
" 3 The Yonkers gneiss of Dinnan quarry
" 4 The dioritic gneiss of Garden quarry

1 **Granite.** The rock is coarse grained and well interlocked. The chief constituents are orthoclase, quartz and microcline.

There are but small amounts of dark minerals, and there is not much decay.

Both surface material and the drill core were examined. The deeper material shows a little calcite, that may be original, occurring in irregular grains. They do not seem to indicate decay. There is a little kaolin alteration of the feldspars, but not to a serious degree. There are no injurious impurities in the rock such as might cause rapid disintegration or discoloration.

The rock is undoubtedly of good grade as to strength, composition and durability.

2 **Gneissoid granite** (Ferris quarry). The rock is of medium grain, containing quartz, the feldspars and a little mica.

There is very little alteration, and no serious decay or injurious constituents. A small amount of sericite and calcite present are not considered of consequence, and as in the case of the granite, the calcite is believed to be original.

The grains are intimately interlocked and the rock is certainly of good quality and very similar to the granite proper.

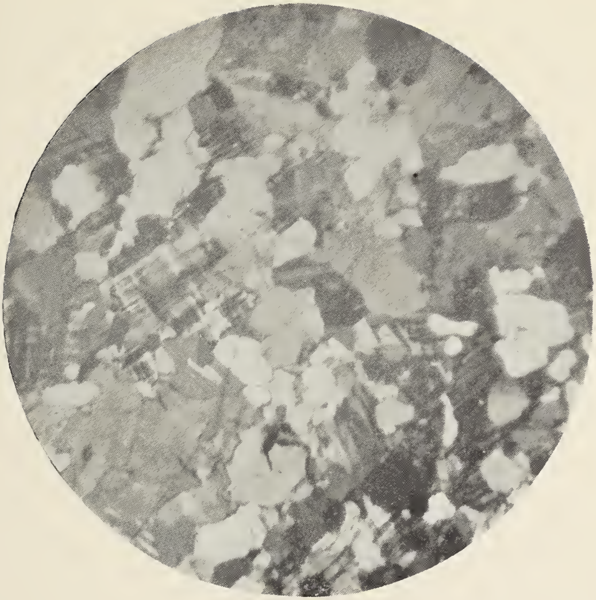
3 **Yonkers gneiss** (Dinnan quarry). This rock is fine grained, and is composed of quartz, mica and the feldspars among which microcline is very abundant.

The condition is good,— very little alteration, close structure, but with a little more granular appearance than any of the other types.

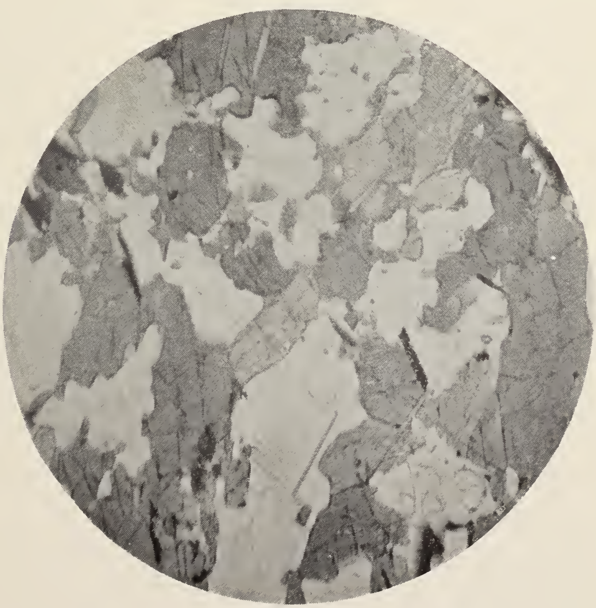
It is a good rock and gives good durability tests.

On badly weathered surfaces the Yonkers gneiss breaks up into a granular product like sand long before it decays to earthy matter. This seems to be caused by expansion and contraction of the different constituents under changing weather conditions inducing a weakening of the sutures. Sometimes there is very little decay even along these sutures, but as they open slightly they become the channels for moisture and staining solutions. This makes the boundaries of the grains very well marked in weathered specimens.

Plate 29



Photomicrograph of Yonkers gneiss of the type to be used in the new Kensico dam. Dinnan quarries. Magnified 30 diameters



Photomicrograph of diorite gneiss from "Garden quarry." Magnification 30 diameters. The constituents are hornblende, biotite, feldspars and quartz.

Such incipient disintegration is common in the more even grained or granular varieties.

The accompanying photomicrograph [pl. 28] is taken in plain light and shows the outlines of the grains due to this cause.

4 **Dioritic gneiss** (Garden quarry). Rock is of medium grain and with a strong tendency to schistose or foliate structure. The dark grains are hornblende and biotite, the light grains are feldspars and quartz.

The rock is fresh, durable and has no injurious constituents. It is good enough for the use in all respects, but has a dark color and is more strongly foliated than any of the others considered.

It is evident from these observations that the rocks considered are all of suitable mineralogic character for the purposes of large dam construction. For very large quantities of material, however, it is probable that neither the coarse granite nor the gneissoid granite could be depended upon for uniform supply. The true regular Yonkers gneiss, however, is very abundant, and can be relied upon for indefinite amounts. The dioritic gneiss is also abundant. The immediate region is not capable of furnishing any better rock than those described above.

Additional tests

Some instructive tests were made by the Board of Water Supply under the direction of Mr J. L. Davis who has charge of the testing laboratories. A few of these applying to the rocks at Kensico are tabulated below.

The tests cover: specific gravity, weight per cubic foot, porosity in per cent, ratio of absorption, per cent water absorbed, ratio of drying 24 and 48 hours, retained water pounds per cubic foot 24 and 48 hours.

In the accompanying tabulation the terms used are subject to the following limitations as to definition:

1 Ratio of absorption, sometimes called porosity, "is the ratio of the weight of water absorbed to the dry weight of the stone."

2 Porosity gives "the actual percentage of the stone which is pore space." "The difference between the dry and saturated weights of the sample is multiplied by the specific gravity of the rock and the product added to the dry weight. This gives the weight the specimen would have provided it contained no pore spaces. The difference between the dry and saturated weights

multiplied by the specific gravity of the rock is then divided by the above computed weight of the poreless specimen. This ratio expressed as a percentage is the actual porosity. Expressed as a formula, the computation is as follows:

$$\frac{\text{(Saturated wt. — Dry wt.) S. G.}}{\text{(Saturated wt. — Dry wt.) S. G. + Dry weight}} = \text{Porosity.''}$$

3 Ratio of drying. An attempt has been made to determine the comparative and actual rates at which the saturated rocks give up the absorbed water under ordinary atmospheric conditions. "The ratio of drying was computed by dividing the weight of water lost during exposure by total weight absorbed. The weight of retained water was computed." The comparison is most useful in rocks of like petrographic general character.

The other terms need no explanation.

TABULATION OF TESTS

Name	No. of specimen	Ratio of absorption per cent	Porosity per cent	Specific gravity	Weight per cubic foot	Per cent water absorbed	Ratio of drying		Retained water pounds per cubic feet	
							24 hours	48 hours	24 hours	48 hours
Granite, Ferris quarry, core No. 461	1 2	0.34 0.31	0.77 0.84	2.66 2.65	164.7 164.0	0.26	49.45	52.8	.224	.210
Gneissoid granite, Ferris quarry, core No. 468	1 2	0.32 0.25	0.81 0.71	2.63 2.65	161.0 162.8	0.28	67.48	69.88	.146	.145
Yonkers gneiss, Dinnan quarry	1 2	0.30 0.39	0.87 1.01	2.64 2.64	163.3 161.0	0.30	88.16	88.16	.057	.057
Dioritic gneiss, Garden quarry, core No. 459	1 2	0.42 0.24	0.68 0.68	2.83 2.86	175.4 174.8	0.21	62.5	62.5	.137	.137
Gneissoid granite, Ferris quarry, surface	1 2	0.37 0.98	0.96 2.50	2.63 2.62	162.5 159.4	1.08	86.7	88.2	.252	.215
Granite, Ferris quarry, surface	1 2	0.44 0.19	1.12 0.50	2.63 2.71	162.3 167.3	0.40	70.0	74.0	.207	.180

Mr Davis concludes from a careful analysis and interpretation of these tests that the Yonkers gneiss is of superior durability.

CHAPTER XV

THE BRYN MAWR SIPHON

Geologic conditions as shown by exploration for a proposed pressure tunnel

Bryn Mawr is a railway station 2 miles northeast of Yonkers. The general features of the vicinity, its topography, succession of formations and the boundaries are shown on the accompanying sketch map which is largely copied from United States Geological Survey Folio No. 83. The Southern aqueduct follows southward along a Manhattan schist ridge until, at a point about a mile northeast of Bryn Mawr, a cross depression of so great width and depth is reached that some special means of crossing has to be devised. Near Bryn Mawr station a gneiss ridge rises and continues southward. The proposed line follows this ridge.

Explorations have been made as usual by drilling to determine if possible whether or not a bed rock pressure tunnel is practicable.

The following questions may be made to cover most of the practical issues of the study:

1 What formations would the tunnel cut?

2 Which of these would show most questionable ground?

3 What portion of the line is regarded as most critical — whose development would show whether or not a tunnel is practicable?

4 What special conditions are shown by drill borings?

5 What interpretation is to be placed on the peculiar results from hole no. 4 where there has been unusually great difficulty in drilling?

6 What experiences in similar ground have a direct bearing on this case?

Formations

The formations that would be encountered in the Bryn Mawr siphon are:

1 Manhattan schist (top), the usual micaceous type, also called Hudson schist in United States Geological Survey Folio 83.

2 Inwood limestone (middle), the usual coarsely crystalline dolomitic and micaceous type, also called "Stockbridge dolomite" in the Folio, same as "Tuckahoe marble," same as "Sing Sing marble," same as limestone at Kensico dam and also at Croton dam.

3 Fordham gneiss (bottom), the usual black and white thinly banded type, a much folded and strongly metamorphosed rock, the oldest of all.

4 Yonkers gneiss, the usual type, gneissoid biotite granite very uniform and granular. This formation is an igneous intrusive that cuts up through the Fordham gneiss and is therefore younger. Whether it is also younger than the limestone and schist is not clear.

5 Quartz veins and lenslike segregations of quartz, also pegmatitic streaks, are occasional occurrences in all of the formations. They are most abundant in the schist, but are seen also in the Fordham gneiss. A similar development was encountered in the limestone in hole no. 40.

6 Glacial drift, chiefly modified drift, partially stratified sand and gravel, reaching more than 125 feet in depth, covers portions of all formations.

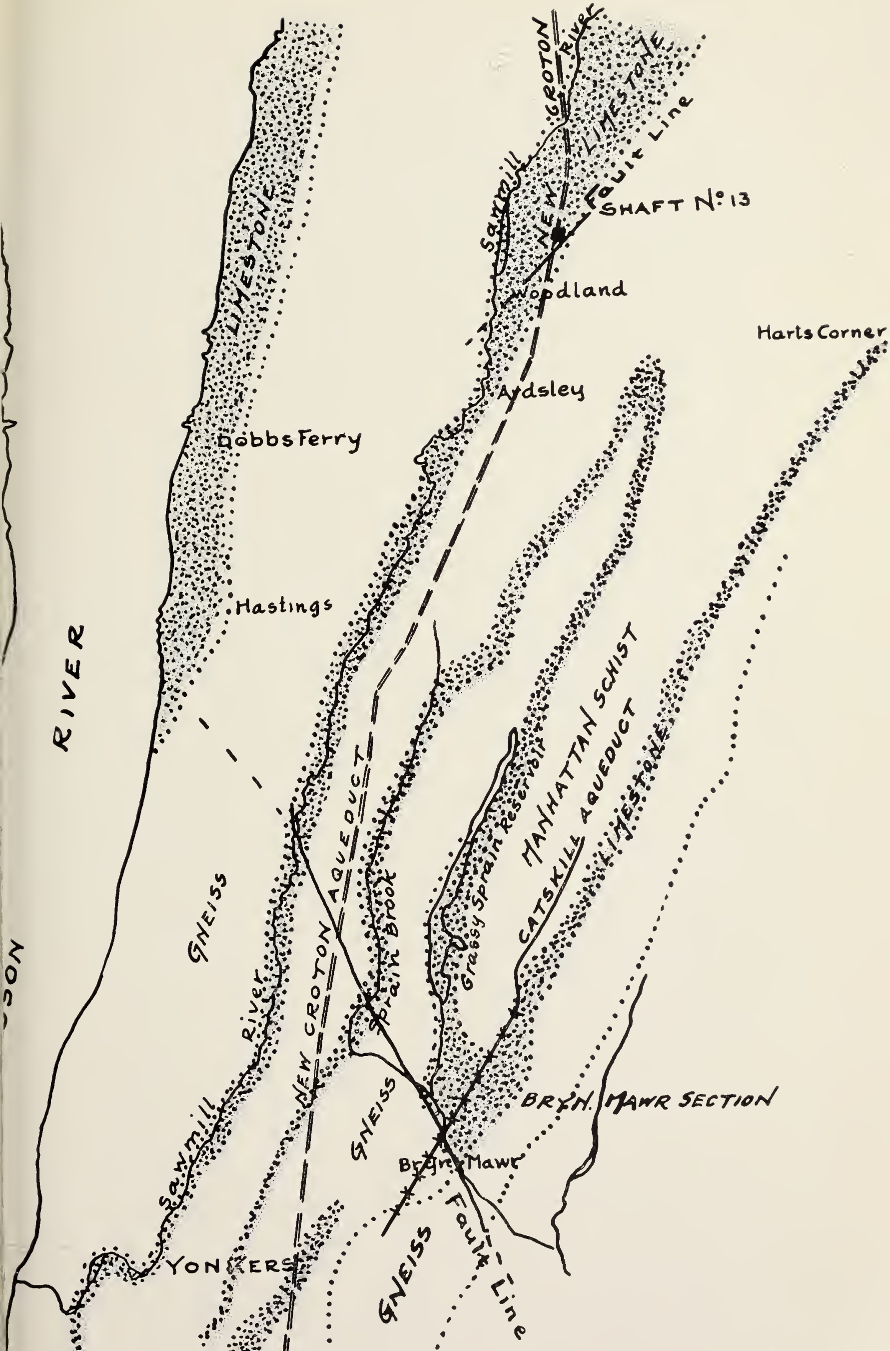
This last formation (no. 6) is the only one that may be wholly avoided in the tunnel proper. The chief interest lies in its hindrance to exploration and its possible usefulness as a source of sand and gravel supply.

Weakest formation. The Inwood limestone is the most questionable ground. This is believed to be so chiefly because of the greater solubility of the rock, its granular and micaceous character, and the probability that a line of displacement accompanied by some fracturing crosses the siphon line in this formation. If a very excessive amount of shattering occurs in this zone it may have induced a condition of disintegration to such depth as to endanger the tunnel.

There are no surface indications of a serious condition at depth for any of the other formations.

Critical zone

The critical zone is probably not far from the contact between gneiss and limestone. There are two reasons for this opinion. The first is related to the nature of the folding. The formations are squeezed into a close syncline pitching northward. In cross section the strata at any point around the head of this trough dip inward, and, because of the more resistant Fordham gneiss forming the floor of the trough, the drainage and seepage and consequent tendency to decay might be expected to follow along its upper contact.



Location map showing by the dotted belts the distribution of Inwood limestone in the Hastings-Yonkers district and the position of the Bryn Mawr tunnel section as well as shaft 13 on the New Croton aqueduct with their relations to the limestone belts. Manhattan schist and Fordham gneiss occupy the rest of the area.

The second reason is related to the probable later faulting movements. It is evident from the map [Folio 83] that the formations in the vicinity of Bryn Mawr are bulged up. One would expect the trough which contains the schist and limestone of Grassy Sprain valley to continue uninterruptedly southwestward and join with Tibbit brook valley. But a cross fold has bulged the formations up so much that for a distance of a mile erosion has removed all of the formations except the gneiss. Bryn Mawr station is about central on this bulge. Evidence of such a movement is readily seen on the gneiss along the northerly margin where it slopes down toward the limestone. The movement had developed a little shearing and has tilted the minor folds downward toward the north at angles varying from 30° to 80° from the horizontal. This angle becomes somewhat more accentuated as the limestone is approached, and it is believed that it may pass a short distance into the limestone border. There is, however, no great amount of crushing evident in the gneiss and this may hold also in the limestone.

The fact that Sprain brook crosses the formations along this northerly margin and flows for 2 miles in a southeasterly direction may indicate a still later movement, probably faulting. There is no surface evidence of it except the abnormal course of the creek. But, if there is such a fault, it also crosses the siphon line in the same zone, i. e. in the vicinity of the limestone-gneiss contact, not far from the location of the present course of the brook.

Therefore it seems reasonable to conclude that the critical zone is near the contact, probably on the limestone side, and in the vicinity of the present course of Sprain brook. It is also probably cut deepest here by erosion. If this zone is in good enough condition to stand tunneling the rest of the line ought to be.

Conditions indicated by borings

All rock formations stand very steep. They vary from 80° to 90°. This means that very few beds can be explored by one hole, and that any weakness or crevice is likely to make a showing in excess of its true proportions.

The cores show considerable crushing. Some of the fractures are not healed, although weathering from circulation is not present on all of them. The micaceous layers are most affected by circulation. Some beds of this variety are considerably weakened even at depths of over 200 feet. Occasional seams have been encountered that give no core at all for several (even 20 or 30) feet. But the

greater proportion of the recovered pieces are comparatively solid even where the total percentage of saving is very low. It is evident that some of the core, a considerable percentage, has been ground to pieces in the process of boring. This is especially noticeable at hole no. 40.

Hole no. 40. Much trouble has been met in this hole. A careful analysis of the record and core and the behavior of the drill is interpreted as follows:

1 Partially assorted drift, chiefly sand and gravel was penetrated for 125 feet.

2 Limestone bed rock of fairly sound quality was struck at about 125 feet (about el. –40).

3 The casing that was put down to shut out the sand failed to reach solid rock, and this permitted a continual supply of pebbles and sand to run into the hole and obstruct the work with each pull up. The presence of these pebbles was also instrumental in grinding the core to pieces, and this accounts chiefly for the low saving.

4 After this opening was plugged up with cement, the drilling was continued successfully until a somewhat broken quartz vein was encountered and this has been followed for about 35 feet. Its broken condition afforded another opportunity for fragments to fall into the hole, and on top of the drill, bringing the work for a second time to a standstill. It is certain also that the drift pebbles still fall in. As the formation stands vertical here it is not surprising that any feature should show an apparent extent quite out of proportion to the real value. The quartz vein is probably of no great breadth. Small seams containing mud may also be followed 15 or 20 feet and still be of no great significance in the formation as a whole. The rock fragments (core) recovered in this hole are fairly sound.

5 In spite of the many delays and difficulties of this hole, it is apparent that the general rock formation is not responsible for it all. The failure to reach solid rock contact with the casing has been the cause of part of it. Later the penetration of a rather rare quartz vein, a thing that would not often be found in the limestone, has added to the trouble. Both of these causes are so rare that they may almost be given the value of accidents.

But the last 100 feet or more of the hole, from depth 225 feet to 335 feet, shows an unusually questionable condition. Only a few rock fragments are saved and they include limestone and quartz vein matter. The rest is wholly disintegration sand of rather complex composition but carrying very much mica. This is all wash

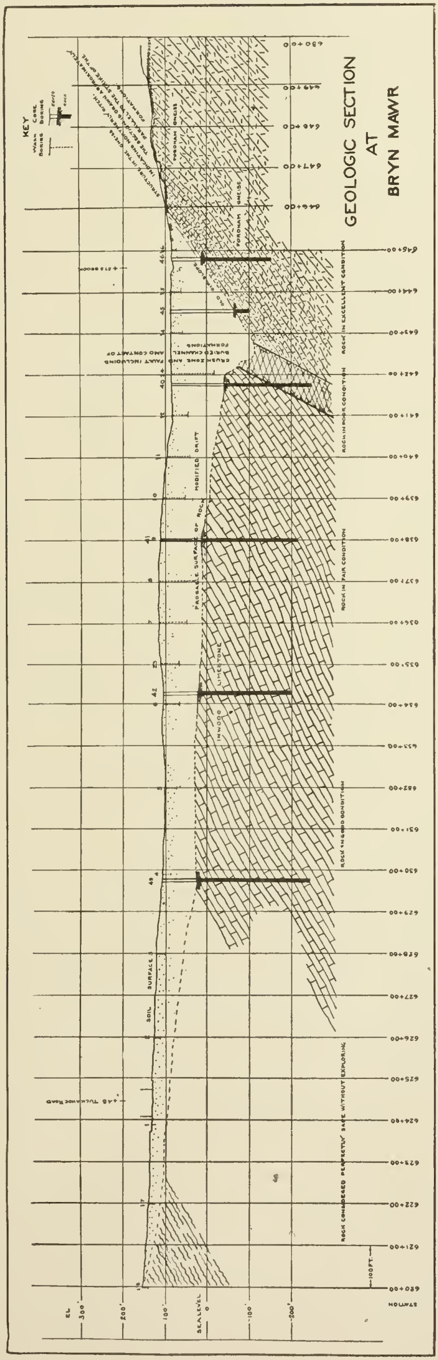


Fig. 36. Section along the aqueduct line from north to south showing the geologic structure interpreted from drill borings

material except one sample, which is a "dry sample" and is still more strongly micaceous.

Borings nos. 40, 45 and 46 are all within the zone that was considered, from surface indications, to be likely to carry the deepest gorge and to show the weakest rock. Because of the heavy drift cover (more than a hundred feet) it is manifestly impossible to locate the weakest zone more closely or judge of its exact condition except by borings.

Hole no. 42 at station 634 + 28, penetrates 82.4 feet of drift and reaches bed rock at about elevation 21 feet A. T. The rock is good, substantial, coarsely crystalline limestone. It shows as sound condition as can be expected in this formation even under the most favorable situations.

Hole no. 46 at station 644 + 77.4 is just south of the brook. It penetrates 72 feet of drift and reaches bed rock at elevation 14 feet A.T. The rock is Fordham gneiss of typical sort and in perfectly good condition. There is no question about the soundness of the rock from this point southward.

Hole no. 45 at station 643 + 52.5, 125 feet north of hole no. 46 penetrates drift for about 150 feet (possibly a few feet less, 145 feet). This drift cover is interpreted as mostly sand (modified drift) to 115 feet and a boulder bed from 115 to 143 feet. After the true ledge is reached it is sound and shows no unusual or questionable conditions. It is Fordham gneiss.

Interpretation

1 **Weak zone.** There is little doubt that this last 100 feet of hole no. 40 is in the decayed weak zone that was expected to develop in the vicinity of the contact between the gneiss and the limestone. It would be expected to pitch northward along the floor of gneiss and extend beneath the southerly extremity of limestone at this point [*see* fig. 36].

2 **Contact.** Hole no. 40 cuts limestone, hole no. 45 cuts only gneiss, therefore the formational contact lies somewhere in this 177-foot space.

3 **Position of old channel.** Bed rock surface is lowest at hole no. 45. But since the rock itself is sound gneiss, it is not believed to represent the lowest possible point. This is still more certain because of the fact that the pitch is northward so that this becomes a dip slope on which the preglacial stream could glide against the edges of the limestone beds [*see* diagram], and because the condi-

tion of the rock a little farther north (at hole no. 40) shows that these limestone beds are actually much weaker than the gneiss. Therefore the deepest portion of the buried channel is to be expected between holes no. 40 and no. 45, and probably nearest to hole no. 40.

4 **Depth of old channel.** How deep the buried channel may be can not be accurately estimated. But if the same dip slope as is shown by the rock surface from hole no. 46 to no. 45 prevails northward toward hole no. 40, a depth somewhat below –100 feet may reasonably be expected. In the absence of data bearing upon the depth of other portions of this ancient channel or of the lower Bronx river with which it must have been connected, it is impossible to estimate more closely.

5 **Interpretation of hole no. 40.** There is so little rock actually saved from the more than 200 feet of possible core on this hole that its real character is very obscure.

There are three possible explanations for the condition found in the last 100 feet.

a The drill may have followed a large mud seam.

b The material may be only residuary rotten limestone still wholly above the gneiss.

c The actual contact may have been penetrated and a part of this rotten material may be decayed gneiss within a crush zone.

The difficulty in drawing absolute conclusions is increased by the fact that matter falling in from above has been a continued source of trouble and is more or less mixed with the rock material of lower points. Therefore, the fact that the sand taken from the lowest points, 335 feet, is silicious instead of calcareous, may not prove satisfactorily that the rock at that point is wholly silicious.

It is worth noting, however, that the harder rock in the upper portion of the hole was in places much crushed and that mud seams were encountered before reaching this last 100 feet.

It is also worth noting that the same dip slope of rock surface as prevails between holes no. 46 and no. 45 if continued northward to hole no. 40, would cut that hole a considerable distance (75 feet) above its bottom.

In view of all the conditions, therefore, it is judged that there is a crush zone here, that hole no. 40 penetrates it, that it is badly decayed, that the plane of the crush zone dips steeply northward and cuts both limestone and gneiss, that a tunnel at about –300 feet would cut this zone south of station 640 and north of station 642, and that all other portions of the line are in comparatively satisfac-

tory condition. This zone for a hundred feet is likely to be wet, weak, and would require extra precautions and additional expense in construction.

6 Evidence of faulting. Whichever interpretation of hole no. 40 is taken is in support of some displacement in the nature of faulting between holes no. 40 and no. 45. If the gneiss rock floor is not reached in hole no. 40, then the greater northward slope of it from hole no. 45 to no. 40 than is shown from no. 46 to no. 45 indicates a downward movement. If on the other hand, the identity of the formation in the lower part of hole no. 40 be considered undetermined, and its condition attributed to decay in a crush zone, the presence of the crush zone itself indicates movement of a fault nature.

Conclusions as to character of the crossing

In considering the geological conditions as a factor in the problem of practicability of a tunnel, it is necessary to note the following points:

1 In view of the fact that the deepest point in the ancient channel is not yet found, and that it will probably go below –100 feet, it would be necessary to figure on a tunnel grade down well toward –300 feet.

2 It would be necessary to figure on a wet and weak zone of at least 100 feet along the tunnel and a more expensive construction at that point.

3 The ground at such depth south of station 642 is unusually sound. The ground north of station 636 may be counted good. The ground between 636 and 640 may be considered fair, and the ground from 640 to 642 +, troublesome, containing the chief elements of uncertainty.

Fig. 36, which is a geologic section along the line at this point, shows the distribution of these features drawn to scale.

CHAPTER XVI

A STUDY OF SHAFT 13 AND VICINITY ON THE NEW CROTON AQUEDUCT

[*See* outline location map, pl. 30]

There has been reference made occasionally in connection with the Bryn Mawr explorations, as well as others, to the remarkable piece of bad ground encountered in 1885 on the New Croton aqueduct near Woodlawn in the Saw Mill valley. This experience has been the source of much misgiving. Because of its evident importance and close relationship to conditions that may exist in the same formation at points on the Catskill line, an examination of this ground was made for the purpose of comparison. The meaning of that case and its bearing on the Bryn Mawr questions are given below:

Engineer's records

This ground and its remarkable behavior is described by Mr J. P. Carson in the Transactions of the American Institute of Mining Engineers, September 1890, pages 705–16 and 732–52.

A description is also given in Wegman's *Water Supply of the City of New York,* 1658 to 1895, on page 152.

From Mr Wegman's report is taken the following:

> The south heading was started from this shaft on June 1, 1885. It advanced at the rate of about 80 feet per month for 392 feet through good limestone rock (dolomite), which then became softer. On December 9, 1885, when the heading had reached a point 407 feet from the shaft a fissure was encountered from which about 100 cubic yards of decomposed limestone clay, sand and dirty water poured into the tunnel, partly filling it for a distance of 125 feet. After three days delay, when only clear water was flowing into the tunnel, the fissure was plugged with straw. The heading was advanced 20 feet further until on December 22, 1885, an outpour three times greater than the first occurred, covering everything in the heading out of sight * * * borings were made on the surface with a diamond drill to determine the extent of the soft ground in front of the tunnel. It was found to lie in a pocket in the rock,

which had a length of 110 feet on the axis of the tunnel and extended for a short distance below the invert of the conduit. The soft material, consisting of sand, gravel, clay and decomposed rock had a depth of about 160 feet from the surface to the top of the tunnel. It exerted such a pressure against the timber bulkhead that the 24-inch oak logs used as "rakers" (braces) became crushed in 24 hours and had to be continually renewed.

The chief points of present interest are that the tunnel, at a depth of about 160 feet from the surface, and after passing through several hundred feet (407 feet) of good dolomite, came into rotten rock and soft ground 110 feet across on the line. It was so soft that it ran into the tunnel in great quantities and exerted such pressure as to make progress in it a very troublesome and costly matter, taking "60 weeks to advance the tunnel 85 feet" and costing "$539 per foot." The material caved in so freely as to form a pit on the surface.

Statement of geologic conditions

It is not possible to interpret the conditions at this locality as fully as one would wish because of the vagueness of some of the statements, but the following facts and explanation are essentially correct:

1 The rock is the Inwood limestone, the same kind and same general conditions as all of the limestone belts that occur in the region of the Southern aqueduct.

2 The soft ground penetrated at the point in question — 407 feet south of shaft 13 — called in the Carson report and others "a fissure" or "pocket," etc., is in reality a fault crush zone. The fault plane probably dips steeply southeast and strikes n. 50° e. cutting the tunnel line at an angle of something like 20°.

3 The point is well up on the side of the valley more than a hundred feet above Saw Mill river, and the strike of the fault zone in its southwesterly extension cuts into the lower portion of the valley, so that underground circulation would be encouraged along the zone in this direction.

4 The limestone outcrops very near by on the west side of the line and the Manhattan schist occurs near by on the east. The attitude of the beds is such as to indicate a fault of the thrust type, The accompanying figure illustrates this relationship in a cross section at right angles to the axis of the tunnel [*see* fig. 37].

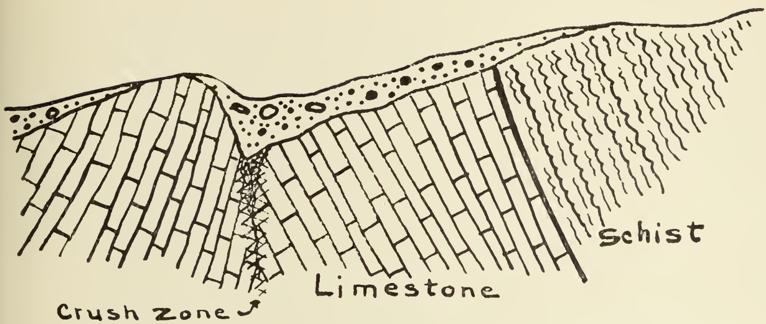


Fig. 37 Sketch of the geologic structure at shaft 13 on the New Croton aqueduct. Interpreted from field observations

5 It would appear probable that this zone was penetrated at the worst possible level, i. e. near enough to its wholly decayed upper part to furnish no resistance at all to the overlying sand and gravel, and not deep enough to reach the more substantial (although probably crushed) rock that may reasonably be expected to prevail at no very much greater depth.

The chief point is that the weak spot has a reason and is not an accidental thing that might be expected just anywhere. But it must be admitted, in spite of this fact, that a casual examination of the locality would not make one suspicious of its existence, and it is surprising that the spot could have caused so much trouble.

From the above it will be seen that in several respects the Bryn Mawr case is somewhat similar to this. They both indicate faulting; they are in the same type of rock; they both show or indicate caving tendencies.

On the other hand, there are certain elements of difference some of which are capable of very materially modifying any conclusion that might be based upon the simple facts of likeness. For example — it should be expected (1) that the fault movement at shaft 13 would be the greater because of lying in the more prominent lines of such displacement of the region, (2) being a thrust movement, the crush effect is probably more prominent at shaft 13 than at Bryn Mawr, (3) occurring at greater elevation above probable circulation outlet, the opportunity at shaft 13 for extensive and rather deep decay is the greater, (4) being cut so near the surface (160 feet), its condition there is not necessarily a reliable guide to the seriousness of decay at a greater depth.

Comparison of Bryn Mawr and shaft 13

The following statements embody an opinion on the points raised or suggested in connection with a reference to the New Croton difficulties at shaft 13. The items are therefore treated by comparison or contrast so far as possible:

1 **Type of rock.** The rock explored at the Bryn Mawr siphon is the same formation as that in the Saw Mill valley cut by the New Croton aqueduct, i. e. the Inwood limestone — sometimes called "Stockbridge dolomite." It is the same also as the other large limestone belts in Westchester county. There are occasional small strips of limestone of another type, but its behavior could not be very different.

2 **Soft material.** "Is any material of this sort" (like that in the New Croton tunnel near shaft 13) "likely to be encountered either in the crushed zone at boring 40 or elsewhere in the limestone belt?"

It is sure to be encountered, especially near hole 40, if that zone is cut shallow. The behavior of the lower portion of this hole is very similar to the described case near shaft 13. The only probability of avoiding it lies in placing the tunnel deep enough to cut more substantial rock. The single hole upon which all this argument is based can scarcely be considered a thorough enough exploration to build up a quantitative statement as to depth or width.

There is no evidence, either on surface or in the exploration holes, of any other such zone on this line.

3 **Depth and extent.** Under the circumstances, the increased depth makes it less probable that so much ground of like behavior would be found. Again, it is not likely that precisely the same conditions would so effectually halt operations or be considered so nearly insurmountable at this time. One of the many serious objections is that the tunnel would have little strength or resistance to a bursting pressure. It must be admitted that if caving ground were penetrated it would prove very difficult to handle with the gravel cover at the depths now considered, i. e. 300 feet or more below the surface.

4 **Water.** "What are the probabilities in regard to the quantity of water to be met in the crushed zone near boring 40? Can any limit be set which it would be extremely improbable that the inflow would exceed, on account of the topography of the country and the nature of the overlying materials?"

There is likely to be much water. Nearly all of the overlying

drift is sand and gravel that is probably saturated and in such condition as to permit easy flow to any lower outlet. It may readily carry 8–10 quarts of water to the cubic foot or about 2 gallons. The area covered by such deposits is about 2500 feet long on the southerly base along the creek and at this margin is approximately 150 feet deep. The northerly margin is variable and reduces in places to 0 feet in thickness. It may, however, really represent 500,000,000 cubic feet of this gravelly material holding 1,000,000,000 gallons of water as a nearly permanent supply.

This overlying material is necessarily a menace of no mean proportions. Every crevice or crush zone remaining unhealed will have water and plenty of it, the inflow being limited only by the size of the cracks and their abundance until the reservoir should be drained. There is no hardpan bottom to act as a dam.

Outside additions to this permanent supply are confined to that received from rain and the stream. The rainfall on the area and immediately available as addition to the underground supply in the lower sands, together with the stream flow, which would probably sink into the sands, if an attempt to drain the underground supply were made, may be expected to furnish additional water at a possible rate of 2500 gallons per minute. How much of all this is available at tunnel level depends wholly upon the openness of structure in the rock. There is nothing else to materially control the permanent and additional supply.

There is evidence in hole 40 of considerable crushing. That means capacity for water circulation, but how much no one can tell. There is also much rotten rock in the same hole. This means that circulation has been easy and effective, but how much now no one can tell. The single hole (no. 40) in the absence of any other corroborative data is not sufficient to base more elaborate or precise quantitative estimates upon.

5 **Solubility.** What is "the nature of the limestone with reference to its resistance to solution?"

This limestone is, as all limestones are, more easily attacked by circulating water than most other rock types [*see* Rondout Valley]. The Inwood limestone such as occurs at Bryn Mawr is crystalline, often contains much mica and then is inclined to be foliated in structure, and it prevailingly stands steeply inclined. Because of these features in which it differs from the Rondout Valley limestones, it is likely to be more generally affected by decay along the zones permitting circulation than any of the Rondout Valley types.

The Rondout Valley limestones are affected along joint planes, but the effect is almost wholly confined to a simple enlargement of these crevices. In the Inwood an additional effect is the weakening of the sutures or bond between the individual granules resulting in a tendency to weaken the whole mass as far as there is much penetration of seeping water. It would have less tendency to produce openings or caves, but greater tendency to produce a rock that would crumble in the hand or that would gradually assume the condition of a lime sand or a micaceous mud.

As to the effect of water from the aqueduct on fresh portions of this rock, it is certain that the rock would be attacked wherever exposed to direct action. Its method of attack is by solution, and the rate of attack may safely be reckoned as not materially different from that assumed or being established by experiment and experience on the Rondout Valley types.

In the final consideration of the difficulties at Bryn Mawr the engineers have decided to abandon the tunnel plan. It is probable therefore that no additional explorations of direct bearing on the problems of this ground will be made.

CHAPTER XVII

GEOLOGICAL CONDITIONS AFFECTING THE LOCATION OF DELIVERY CONDUITS IN NEW YORK CITY

Hill View reservoir is the terminus of the Southern aqueduct. The Catskill water is to be delivered at this point, just north of the New York city line on the Yonkers side, at an elevation of 295 feet. From this reservoir the water is to be distributed by an independent system of conduits to the principal centers of consumption in lower Manhattan and Brooklyn.

It is believed that distribution can be most economically made and the system be most permanently established by constructing the main trunk distributaries as tunnels in solid bed rock at considerable depth below all surface disturbances.

Preliminary investigations have been carried on by Headquarters department, Mr Alfred D. Flinn, department engineer, beginning in 1908. As the active work of exploration was entered upon Mr William W. Brush, department engineer, was assigned to this special division of the department's work and most of the preliminary exploration borings were planned and finished under his immediate supervision. With the resignation of Mr Brush to take the post of deputy chief engineer in the Department of Water Supply, Gas and Electricity, Mr Walter E. Spear, department engineer, was secured to continue the difficult work of finishing explorations and preparing for construction.

Studies of conditions affecting such a system and explorations designed to test the ground in line with these studies[1] have been made. The work thus far done in an exploratory way has been confined to one main distributary.

Section A. Preliminary geological study

As a preliminary step toward the systematic study of local conditions affecting possible conduits, trial lines were laid out on the

[1] Few engineering enterprises, probably, have been planned with so careful regard for all known geologic conditions. The geologist and the engineer worked alternately on the same problems until, in the opinion of both, the best possible line was selected. It is the writer's belief that so systematic a method has seldom if ever been carried out in engineering work of this kind. On this account, and in part to illustrate some of the preliminary stages in such work, many of the original facts and arguments and suggestions are given without change in the following discussion.

city map from Hill View reservoir to Brooklyn by three different routes. So far as the topography and city development and other engineering considerations could be forseen either route could be used. Studies of all kinds were expected to indicate which would be the most favorable and whether or not it might be advisable to shift even the best one to still more favorable ground. These are shown on the accompanying map which also covers the local geology of the immediate vicinity of the lines [*see* pl. 32].

General questions

When the problem of the practicability of a rock tunnel for distribution conduits was first studied, several general questions were raised which indicate the lines of investigation followed.

1 What is the character of the rock along the projected conduit lines shown at the depths required for such tunnels?

2 Will the rock at moderate depths be such as to permit successful and economical construction of tunnels to be used under the hydraulic pressure due to Hill View reservoir?

3 Does the character of rock in the vicinity of the lines vary sufficiently to materially affect the cost of a tunnel if the lines be shifted approximately 1000 feet either way from those shown on the original map as trial lines?

4 Are the suggested locations of conduit lines adapted from a geological viewpoint to the construction of pressure tunnel conduits, and, if not, what changes in these lines would be advisable?

5 Is the thickness of rock covering sufficient at all points to obviate trouble from open seams and disturbed surface rock?

6 What borings and other field investigations should be undertaken to determine the practicability of construction of pressure tunnels along the lines suggested?

In line with this series of questions a thorough geological investigation was begun, the chief conclusions of which are given below.

Geological formations

There are six local formations of sufficient permanence and individuality of character and of sufficient areal importance to be treated as units in this study. These are described in some detail in part 1, but for convenience are briefly listed as follows:

1 Glacial and postglacial deposits of boulders, clay and sand, with silt beneath the rivers.

Plate 31

A relief map of New York city and environs. Reproduced from a model by Howell.

2 Manhattan schist, the most abundant formation, chiefly mica schist with very subordinate hornblende schists, and usually with abundant pegmatite lenses and veins.

3 The Inwood limestone, a white, dolomitic marble when fresh, which shades into impure, micaceous varieties.

4 The Fordham gneiss, varying from a thinly schistose or quartzose rock to a strongly banded or a very massive and much contorted gneiss. The oldest formation of the district.

5 The Yonkers gneiss, an original intrusive granite, now squeezed into a gneiss. Younger than the original Fordham.

6 The Ravenswood grano-diorite or as it might be called in engineering practice, granite; an original, intrusive rock now somewhat gneissoid from pressure. Younger than the original Fordham.

The Manhattan schist, the Inwood limestone and the Fordham gneiss are cut by veins or dikes of coarsely crystalline granite, technically called pegmatite. They are of irregular distribution and do not affect the tunneling operations one way or another.

All the formations older than the glacial drift have been compressed into a series of northeast and southwest folds, and all have as a rule a steep or almost vertical dip. The axes of the folds are not horizontal, but usually pitch downward to the south at low angles. Erosion has developed a series of ridges trending northeast and southwest. The limestone being a softer and more easily eroded rock, almost always underlies the valleys or flats and the river channels. It is certain also that there is some faulting.

Rock at depth

The distribution of geological formations along the proposed lines has been shown on the accompanying map [pl. 32]. In general the kind of rock at tunnel depth will be the same as at the surface as indicated on the map for each point. Such error as there is, arises from two causes: (*a*) Uncertainty as to the exact location of some of the contact lines between two formations (usually due to drift cover), and (*b*) dip and pitch of the strata.

In the first case (*a*) where the drift is particularly heavy, it is sometimes impossible to fix a contact line accurately from surface features alone.

In the second case (*b*) it must be appreciated that nearly all of the formations dip eastward at a very steep angle, so that a formation would usually be found to extend a little further east at depth than at the surface. And also all formations pitch southward, so

that they would be found to extend considerably farther south at depth than their surface outcrops. This angle of pitch is from 10° to 30°.

In nearly all these cases, however, the obscurity of the actual surface boundaries is as great a source of uncertainty as the effect of dip and pitch, so that the boundaries as mapped may be considered sufficiently accurate for this comparative study of the lines.

It is worth noting that the rock at the proposed depths of tunnels would be, as a rule, more substantial than at the surface. But there are several places on all of the lines where the exact condition is unknown at the surface as well as at depth. The chief points of this character will be noted in a later paragraph.

Comparison of lines[1]

A comparison of the three lines submitted as the basis of examination — (*a*) the westerly one, (*b*) the central one, (*c*) the easterly one [*see* accompanying map, pl. 32], as to rock formations likely to be cut by them, furnishes the following figures:

Line A. Going southward from Hill View reservoir

Feet	
6 200	Yonkers gneiss — good rock
1 400	Fordham gneiss
1 400	Probably largely Inwood limestone with one weak zone (at Van Cortlandt lake)
5 600	Fordham gneiss — good rock
2 400	Near contact with limestone, probably in gneiss
1 600	Crossing Harlem river — Inwood limestone
4 000	Inwood limestone — probably fairly good rock
800	Inwood limestone — probably containing bad zone to Speedway
16 400	Manhattan schist (to 135th st.)
2 000	Along contact between schist and limestone
4 200	Inwood limestone with one weak zone (to s. end of Morningside Park)

[1] The statements of quality and extent of certain formations and zones are capable of some modification as exploratory work progresses. Some of these are noted in later sections of this report under special headings, such as The Lower East Side, and The East River-Brooklyn section. For the present purpose, as showing the development of the geologic basis of the project it seems preferable to leave the accompanying comparisons in their original form as presented to the board.

12 800 Manhattan schist probably good quality (to s. end of Central Park)

21 000 From Central Park to East river — no outcrops — mostly Manhattan schists at tunnel depth. Condition largely conjectural[1] — probably mostly good rock with occasional weak zones

6 000 Manhattan island to City Hall, Brooklyn. Containing an unknown[1] zone in the East river and unknown quality of rock in Brooklyn.

Summary of Line A

Feet	
6 200	Yonkers gneiss
7 000	Fordham gneiss
2 400	Contact (probably in gneiss)
12 000	Inwood limestone
2 000	Contact (probably in limestone)
29 200	Manhattan schist (good)
21 000	Estimated Manhattan schist (fair)
6 000	Almost unknown
85 800	total

Line B. Going southward from Hill View reservoir

Feet

8 000 Yonkers gneiss — good quality

13 000 Fordham gneiss — good quality

6 800 Inwood limestone, probably mostly in fair condition, except at two points (to Cromwell av.)

6 600 Inwood limestone, unknown condition, but probably largely poor (to Harlem river)

600 Inwood limestone — unknown condition (Harlem river)

4 600 Inwood limestone — unknown condition — probably fair (to Mt Morris Park)

800 Manhattan schist, good

800 Probably Manhattan schist — unknown

2 800 Inwood limestone — unknown condition — probably at least one bad zone (to 106th st.)

12 000 Manhattan schist along Central Park — good

[1] Explorations since conducted by the Board of Water Supply have proven the quality and character of the rock floor at these places. For the revised statement on these sections see the special discussions.

Feet	
8 600	To Broadway — Manhattan schist (little known excep[t] from tunnels already made)
14 000	To East river, probobly Manhattan schist (same as line A)
6 000	Manhattan island to City Hall, Brooklyn — uncertain condition (same as on line A)

SUMMARY OF LINE B

Feet	
8 000	Yonkers gneiss — good quality
13 000	Fordham gneiss — good quality
21 400	Inwood limestone — variable quality
12 800	Manhattan schist — good quality
23 400	Estimated Manhattan schist — fair
6 000	Almost unknown
84 600	total

Line C. Going south from Hill View reservoir

Feet	
6 000	Yonkers gneiss — good rock
17 400	To Webster av.— Fordham gneiss — good rock
5 000	Along contact between limestone and gneiss
9 800	To 138th st.— Inwood limestone with probably two bad zones
1 800	To Bronx kills — along contact between limestone and gneiss — uncertain quality
600	Across Bronx kills — mostly in limestone containing a fault zone — probably bad ground
6 400	Crossing Randall's and Ward's islands and Little Hell Gate. Nearly all is Manhattan schist of good quality
1 000	Crossing Hell Gate — Inwood limestone
1 200	Crossing Hell Gate — Fordham gneiss of good quality
1 800	Astoria point — probably Fordham gneiss of good quality
1 000	Crossing another limestone belt
1 000	To Vernon av.— Fordham gneiss of unknown quality containing one fault zone
7 000	To Nott av.— Ravenswood grano-diorite — good rock
2 800	To Borden av.— Probably Ravenswood grano-diorite.
18 400	To Fort Greene Park Brooklyn — almost wholly unknown but contains probably 5000 or 6000 feet of poor ground

SUMMARY OF LINE C

Feet	
6 000	Yonkers gneiss — good quality
17 400	Fordham gneiss — good quality
6 800	Along contact between limestone and gneiss (questionable)
12 400	Inwood limestone — with several bad zones
6 400	Manhattan schist — probably good quality
3 000	Fordham gneiss — probably good quality
1 000	Fordham gneiss — unknown quality
9 800	Ravenswood grano-diorite — mostly very good rock
18 400	Almost wholly unknown
81 200	total

Tabulated summary — Types of rock formations

	LINE A (WEST)		LINE B (CENTRAL)		LINE C (EAST)	
	Feet	Per cent	Feet	Per cent	Feet	Per cent
Yonkers gneiss	6 200	(7.2)	8 000	(9.4)	6 000	(7.3)
Fordham gneiss	7 000	(8.1)	13 000	(15.3)	21 400	(26.3)
Contact zones	4 400	(5.1)	0	(0)	6 800	(8.3)
Inwood limestone	12 000	(13.9)	21 400	(25.3)	12 400	(15.2)
Manhattan schist	50 200	(58.5)	36 200	(42.6)	6 400	(7.8)
Ravenswood grano-diorite	0	(0)	0	(0)	9 800	(12.0)
Unknown	6 000	(7.0)	6 000	(7.0)	18 400	(22.6)
Total length	85 800	......	84 600	......	81 200	......

Summary of quality

	LINE A		LINE B		LINE C	
	Feet	Per cent	Feet	Per cent	Feet	Per cent
Good rock, 1st grade	42 400	(49.4)	33 800	(40.0)	39 800	(49.0)
Probably fair, 2d grade	30 800	(35.9)	34 800	(41.1)	13 600	(16.7)
Probably poor, 3d grade	6 600	(7.7)	10 000	(11.8)	9 400	(11.6)
Almost unknown	6 000	(7.0)	6 000	(7.1)	18 400	(22.7)
	85 800	100.0	84 600	100.0	81 200	100.0

Argument on choice of line

In judging the quality of rock and its suitability for this conduit the factors of most weight are the same as those repeatedly mentioned in connection with other portions of the Catskill aqueduct line. That is, in brief, that the harder crystalline rocks of the Fordham gneiss and Manhattan schist types wherever known to be

free from fault crushing and surficial weathering are the best variety; that the more heavily buried areas of these rocks, together with those limestone areas that are known to be the most substantial of its class, should be regarded as fair or second grade; that the more obscure areas of limestone and all portions crossing faults or rivers or crush zones in any rock must be regarded as poor or third grade. This rating is based wholly on rock character and without any consideration of cost of construction.

From the above it is clear that line A has more "first grade" rock than either B or C and less "third grade" ground.

Line C has three times as much "unknown" ground as either B or C and less "first" and "second grade" rock.

In other words, the three lines are estimated:

	LINE A Per cent	LINE B Per cent	LINE C Per cent
First grade rock	49.4	40.0	49.0
Second grade rock	35.9	41.1	16.7
First and second grades together	85.3	81.0	65.7
Third grade rock	7.7	11.8	11.6
Unknown ground	7.0	7.1	22.7

In addition to these differences of quality, it appears from a study of the areal geology along the respective lines that a tunnel would pass across limestone contacts from one formation to another six times on line A, four times on line B, and seven times on line C. These may all be considered points of probable weakness.

All of the lines cross belts of well known weakness believed to represent fault zones. Line A crosses three such zones, line B crosses two, and line C crosses at least three.

Furthermore, all of the lines cut limestone for greater distances than seems desirable or necessary. The weakest ground and the most uncertain quality of ground that can be mapped falls within the limestone areas. In this respect line A with 13.9% of limestone ground is preferable to line B, with 25.3% or line C, with 15.2%.

From the above it is apparent that line C is least defensible. Line A has some advantage over both of the others, especially in quantity of first grade rock quantity of first and second grade together, low amount of the known poorest grade and small extent of the so called "unknown" ground.

The chief advantage of line A over line B lies in its much smaller limestone area (12,000 feet *vs.* 21,400 feet or 13.9% *vs.*

25.3%), and the chief advantage of line A over line C lies in its much smaller amount of "unknown" ground (6000 feet *vs.* 18,400 feet or 7.0% *vs.* 22.6%). On these grounds line A is the least objectionable of the three lines proposed.

But it is also clear from an examination of the field, as is shown on the accompanying map [pl. 32], that it is possible to avoid some of these objectionable features or certain parts of them and materially improve the figures by shifting the line to a sort of compromise position between line A and line B. This compromise line, or the trial lines from which the final tunnel line may result, should follow as closely as possible the gneiss and schist ridges and should avoid the limestone areas and known weak zones wherever possible.

Depth of tunnel

The rock formations in general at the required depths are no more objectionable on Manhattan island or in The Bronx than at other localities on the Southern aqueduct. There are weak places and crush zones to be crossed and some of them can not be avoided by any possible manipulation of the line, but these most questionable spots constitute but a small proportion of the whole distance. The depth most suitable must depend chiefly upon the depth necessary at the worst spots.

Comparative cost of construction if lines are shifted

The question is best answered by reference to the geological map. It will be noted especially that the belts of the different rock formations are usually narrow, and that they run nearly parallel to the average direction of the lines. Therefore a shift of line to no great distance would at many points place it within an entirely different formation. It is also notable that all of the lines run along or near the contacts between formations for long distances. At such points a very small shift would wholly change the type of rock and rock quality. Some shifting is desirable.

In general it may be assumed that the limestone belts would be easiest and cheapest to penetrate wherever they are fairly substantial, but they undoubtedly also contain the greater proportion of weak and troublesome ground and must be considered least desirable from the standpoint of maintenance and durability. The gneisses are probably most expensive to penetrate and the schists, medium. Both are more expensive than limestone but both are more likely to prove acceptable for other reasons.

The question of shifting the lines is a complicated one and hinges more upon rock conditions, durability, and location of weak zones, than on any possible cost.

Advisable changes in lines

None of the suggested lines are defensible from a geologic point of view for the reason that a much better one may be obtained by no very serious shifting.

In the general consideration of relative advantages of different possible locations of the line, it is believed that the following large features are of most immediate importance:

1 The ridges as opposed to the valleys.

2 The hard formations as opposed to the softer ones.

3 The crossing of few contacts as opposed to crossing many.

4 The location well within a formation as opposed to location along a contact zone.

It is distinctly preferable from a geologic standpoint (1) to follow the ridges, (2) to keep in the hard formations, (3) to avoid many changes from one formation to another, (4) to keep away from contact zones, and (5) to avoid weak zones, if possible, or cross known troublesome zones at the most advantageous point.

Recommendations of new lines F, G, H, I

The original lines A, B and C are marked on the map in blue [pl. 32]. In addition several trial lines are sketched in yellow, any one of which would give better geological conditions than any of the three original lines. The newly suggested trial lines differ from each other chiefly in the points at which they cross the limestone belts and weak zones. In all of them the central idea has been to follow the gneiss and schist ridges as persistently as possible. All unite at Central Park and are intended to follow Fifth avenue, Broadway, the Bowery and Market street to East river along one of the original lines. North of Central Park they differ from the original lines. The westerly one crosses the Harlem river at 176th street and may be designated line F. The easterly line may also cross the Harlem river at 176th street and may be designated line G; or it may continue southward and cross the Harlem at 155th street. It will then join the first one in the vicinity of 144th street and is called line H. The alternative easterly one which crosses the Harlem at 155th street and follows Seventh avenue to Central Park is line I.

Details of rock conditions along these lines are as follows:

Line F. (Westerly) beginning at Hill View reservoir

Feet	
7 600	Yonkers gneiss — good quality
15 000	Fordham gneiss — good quality
2 000	Fordham gneiss — probably 2d grade
1 200	Harlem river crossing — partly limestone — 3d grade
14 800	Manhattan schist — good quality
1 600	Manhattanville crossing — 3d grade — some limestone
2 600	Manhattan schist — good rock — through Morningside Park
800	At south end of Morningside Park — perhaps some limestone — 2d grade
1 400	Manhattan schist — good — to junction
12 000	Manhattan schist — along Central Park — good
20 600	To East river — Manhattan schist — less known[1] — (fair) (2d grade)
6 000	To Brooklyn "unknown"[1]
85 600	

Line G

Feet	
8 400	Yonkers gneiss — good rock
17 600	Fordham gneiss — good rock

which brings it to the Harlem river where the other line (F) is joined. Although the line is about 1400 feet longer, it avoids some low ground (2000 feet) along the east bank of the Harlem river, some of which may be in poor condition. Total length of line, 87,000 feet.

Line H

Feet	
8 400	Yonkers gneiss — good quality
23 800	Fordham gneiss — good quality — to Harlem river
1 000	Crossing Harlem river — probably fault zone in gneiss
800	Fordham gneiss — good quality
1 000	Limestone — 2d grade
1 200	Manhattan schist — good quality — to junction with the first line (F) at 145th street

From this point the line is the same as F and G. Its chief advantage is the great distance which it has in Fordham gneiss.

Total length of line, 85,600 feet.

[1] Subsequent explorations made by the Board of Water Supply have eliminated this unknown ground. *See* later discussion.

Line I

Feet	
8 400	Yonkers gneiss — good quality
23 800	Fordham gneiss — good quality — to Harlem river
1 000	Crossing Harlem river — probably fault zone in gneiss
4 400	Fordham gneiss — good rock — to 135th street
4 600	Inwood limestone — probably fair — 2d grade
2 000	Inwood limestone — probably poor quality — 3d grade
1 000	Manhattan schist — good quality

At this point the line unites with line F. Total length of line, 83,800 feet.

A tabulation of these figures indicating estimated extent of rock types is given below:

	LINE F Feet	LINE G Feet	LINE H Feet	LINE I Feet
Total length of line	85 600	87 000	85 600	83 800
Length in Yonkers gneiss	7 600	8 400	8 400	8 400
Length in Fordham gneiss	17 000	17 600	25 600	29 200
Length in Inwood limestone and marginal contacts	3 600	3 600	3 400	6 600
Length in Manhattan schist	51 400	51 400	42 200	33 600

Comparative summary of types of formation (Comparative distances are expressed in percentages)

	A	B	C	F	G	H	I
Yonkers gneiss	7.2	9.4	7.3	8.8	9.6	9.8	10.0
Fordham gneiss	8.1	15.3	26.3	19.8	20.2	29.9	34.8
Contact zones	5.1	0.0	8.3	4.2	4.1	3.9	7.8
Inwood limestone	13.9	25.3	15.2				
Manhattan schist	58.5	42.6	7.8	60.0	59.0	49.3	40.1
Ravenswood grano-diorite[1]	0.0	0.0	12.0	0.0	0.0	0.0	0.0
Too little known to classify[1]	7.0	7.0	22.6	7.0	6.9	7.0	7.1

[1] The Ravenswood granodiorite has been proven by later explorations to extend into the territory here marked as too little known to classify.

As a group it is especially noticeable that the new lines F, G, H, I, have a very much lower percentage of contact zones and limestone. The percentages of gneisses have been notably increased, and the unknown and questionable formations have been reduced to approximately the lowest terms.

Estimated summary of quality

	LINE F Feet	LINE G Feet	LINE H Feet	LINE I Feet
Good rock, first grade	53 400	56 800	54 600	49 600
Fair " second "	23 400	21 400	22 400	25 200
Poor " third "	2 800	2 800	2 600	3 000
Unknown[1] (Brooklyn)	6 000	6 000	6 000	6 000
	85 600	87 000	85 600	83 800

[1] All of this rock is now known to be of good quality.

In other words these new lines show:

	LINE F Per cent	LINE G Per cent	LINE H Per cent	LINE I Per cent
First grade rock	62.3	65.3	63.8	59.1
Second "	27.3	24.6	26.1	30.0
First and second grades together..........	89.6	89.9	89.9	89.1
Third grade rock.........................	3.2	3.0	3.0	3.6
"Unknown" ground[1]	7.0	6.9	7.0	7.1

[1] Results of recent boring explorations show that this ground is first grade also.

A comparison on this basis with the original lines A, B, C indicates that these new lines F, G, H, I, make a better showing, especially on first grade rock and that all show decided reduction in the third grade ground.

	A	B	C	F	G	H	I
First grade rock................	49.4	40.0	49.0	62.3	65.3	63.8	59.1
Second grade rock	35.9	41.1	16.7	27.3	24.6	26.1	30.0
First and second	85.3	81.0	65.7	89.6	89.9	89.9	89.1
Third grade rock...............	7.7	11.8	11.6	3.2	3.0	3.0	3.6
Unknown[1]......................	7.0	7.1	22.7	7.0	6.9	7.0	7.1

[1] Now known to be first grade.

On geological grounds, therefore, it is confidently believed that any one of the new lines (F, G, H, I) would give decidedly better results than any one of the original ones (A, B, C). The poor and the questionable and the unknown ground can not be wholly avoided by any possible line, no matter how roundabout. In these lines, approximately as drawn, the objectionable points are reduced to a minimum with almost no increase in total length of conduit. The objectionable portions are also restricted in large part to the

Harlem river, where we already have the experience of the last aqueduct (the New Croton aqueduct) as a guide, and a very few other spots.

General conclusions

Line I is the shortest possible defensible line. Its chief objectionable feature is a rather long stretch, 6600 feet of limestone, from 135th street to Central Park, upon the quality of which there are no data. It crosses the Harlem river fault probably in gneiss. But it crosses the extension of the Manhattanville fault in limestone.

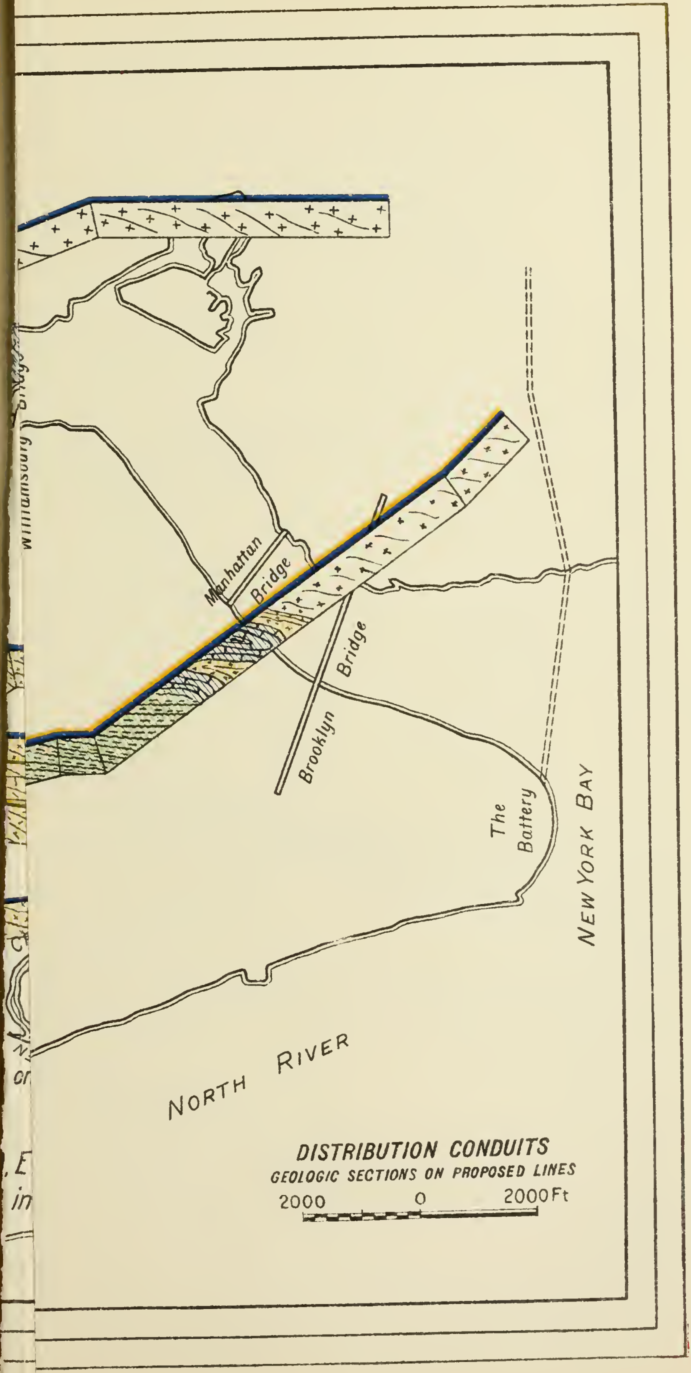
Lines F, G and H are almost equally defensible. Line G is longest, but is in some respects — especially in following the ridge crests — one of the best possible locations.

It should be appreciated that many other matters, such as municipal works already completed or projected, or matters of engineering practice, are likely to make it necessary to modify any line proposed, and that the final line is more likely to be a compromise, considering all interests.

A graphic representation of the comparative merits of the proposed lines is given in plate 33. This is strictly a geologic study. The lines are properly placed on an outline map of the city corresponding exactly to those drawn on the geologic map, plate 32. The geologic formations that each would cut are represented on longitudinal sections which follow each line, and the attitude and structure of each formation are indicated.

Revised lines

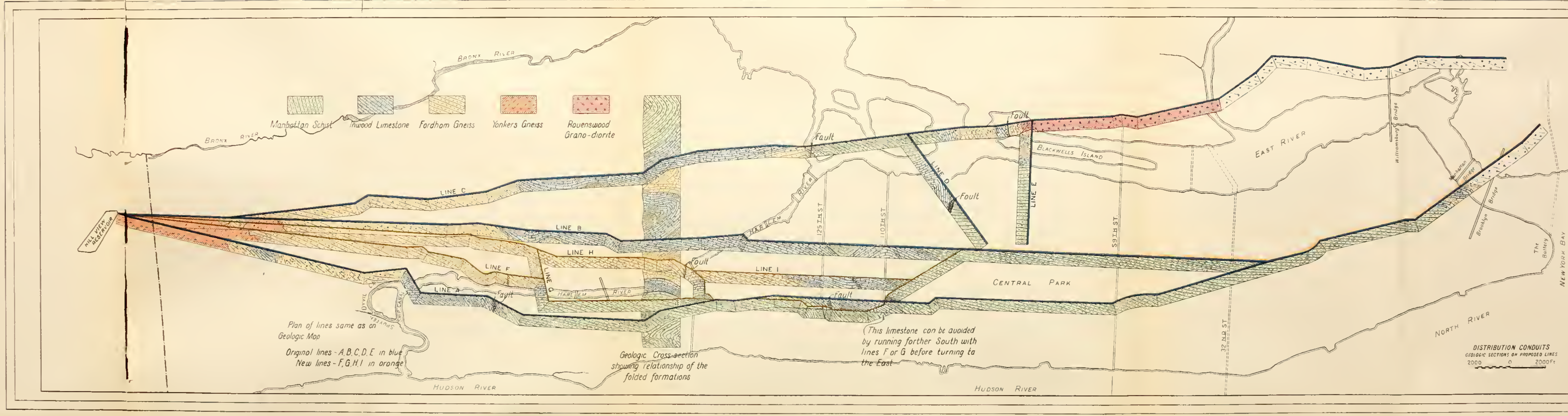
Subsequently two revised lines based upon the preceding studies were examined to determine preference. Later one of these, or a slight modification of it, was adopted as the one to be explored. It was soon determined on the same reasoning as was applied to the first group of lines that the most westerly line — the line keeping as much as possible within the gneiss and schist ridges — would be the most likely to give satisfactory conditions. By this method of selection the unknown or untested and doubtful ground was reduced to its lowest limits. It was found that nearly all of the very weak spots could be located by inspection in the northern portion of the line, but south of 59th street the question is decidedly more difficult because of the heavy drift cover. No rock outcrops occur south of 30th street, and one is reduced to the evidence of deep borings.


Manhattan
Bridge
Brooklyn
Bridge
The
Battery
NEW YORK BAY
NORTH RIVER
DISTRIBUTION CONDUITS
GEOLOGIC SECTIONS ON PROPOSED LINES
2000
0
2000 Ft

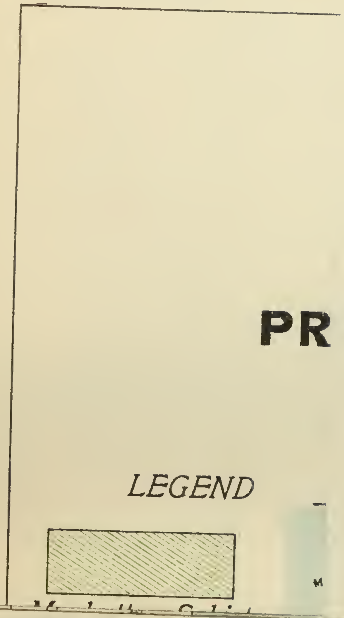

City of New York
BOARD OF WATER SUPPLY
CATSKILL AQUEDUCT
GEOLOGIC DETAIL OF LOWER EAST SIDE
OCTOBER 18, 1910
200 0 200 400Ft
ELEV.
Drift surface
Glacial Drift
Rock Floor
Decayed Rock
Manhattan Schist
Inwood Limestone
Fordham Gneiss Series with occasional limestone bed
Fordham Gneiss Series with many narrow Interbedded Limestones
Fordham Gneiss Series mostly granodiorite
Probable Sound
Schist = S
Limestone = L-LS
Gneiss = G
Recovery over 25% shown thus
Recovery under " " "
No Recovery " "
The lower profile line is intended to mark the limit of rock decay as interpreted from borings. Each prominent depression probably indicates a crush zone belonging to a fault
NOTE – Borings are projected parallel to strike on line joining hole #28 and hole #5. Approximate bearing of strike is N25°E
ELIZABETH
THE BOWERY
DELANCEY ST.
BROOME ST.
CHRYSTIE
FORSYTH
ELDRIDGE
ALLEN
ORCHARD
LUDLOW ST.
ESSEX ST.
NORFOLK ST.
SUFFOLK ST.
GRAND ST.
HESTER ST.
CANAL ST.
EAST BROADWAY
HENRY
MADISON
JEFFERSON
MONROE
CHERRY
WATER
SOUTH ST.
CLINTON ST.
MONTGOMERY ST.

GRAPHIC GEOLOGIC STUDY
OF THE
ALTERNATIVE LINES
FOR THE
NEW YORK CITY
DISTRIBUTION CONDUIT

The attitude of the different formations and their approximate amounts are indicated by longitudinal sections along the alternative lines whose courses are indicated in detail on the accompanying geologic map.



EDUCATION DEPARTMENT
JOHN M. CLARKE
STATE GEOLOGIST



Points for exploration north of 59th street

It was soon evident that extensive exploratory work would have to be undertaken and the following points were selected at which to begin.

1 The Harlem river crossing, where the distribution conduit line crosses the river just below High Bridge [*see* later description]. The only good evidence as to character of rock at this place is from the pressure tunnel of the New Croton aqueduct which crosses the river a short distance above.

2 The Manhattanville cross valley (125th street depression). This is the most important cross depression on the island of Manhattan. It is apparent after a little investigation that the bed rock floor lies deep and that if it were not for the drift filling the tides would surge through this valley making a direct connection between the Hudson and East river. It was the least known as to depth and character of any point along the proposed line.

3 The depression between Morningside and Central Park. At that place limestone on the crest of a pitching anticline reaches farther south than on either side and is more deeply eroded. The other zones of large importance are in southern Manhattan the geology of which is a special study.

CHAPTER XVIII

AREAL AND STRUCTURAL GEOLOGY SOUTH OF 59TH STREET

The necessity for exploration in certain sections of this area can not be appreciated without a statement of the local geology and especially of the revision of both areal and structural geology that the writer has based upon an exhaustive study of all the available drill cores and other data to be found in southern Manhattan, East river and Brooklyn.

Below Central Park there is now little geology to be gathered from a study of the present surface. But as far south as 31st street the bed rock geology is pretty well known from earlier reports and from recent improvements that have exposed the underlying rock. All of this portion is mapped as Manhattan schist except one small area of serpentine at 59th street between 10th and 11th avenues. There is no reason to modify this usage. A careful study of a great number of rock borings from the Pennsylvania Railroad tunnel across Manhattan at 32d street proves beyond question that bed rock is Manhattan schist, including almost all known variations and accompaniments, for the whole width of the island along that line.

Still farther southward the points that have yielded exact information about bed rock are less numerous, and below 14th street are confined to deep borings or an occasional very deep excavation for foundations. Even these sources of information are lacking over large areas. The greater number of borings available are along the water front. Their distribution is such as to indicate that the west side and central portion and southerly extremity of the island are all underlain by Manhattan schist. This is true eastward to the East river at 27th street, and as far eastward as Tompkins square at 10th street and almost to the Manhattan tower of Brooklyn bridge in that vicinity.

To the eastward of these limits, i. e. to the eastward of the line projected from Blackwell's Island to the Manhattan tower of Brooklyn bridge, there is a more complicated geology. The borings of the East river water front are decidedly variable. They are certainly not all Manhattan schist of the usual types. Those most unlike the Manhattan are at the same time most like some varieties

of the Fordham, and indicate that these formations both occur. The lack of any data in the beginning of this investigation except on the water front made it impossible to draw more than very general lines. Drawn in this way, the lines of course are too straight, but it is certain that they indicate more nearly the actual existing areal distribution of formations than any of the maps now in existence.[1] They indicate a southward extension of the Blackwell's Island belt of Fordham gneiss toward the Manhattan tower of Brooklyn bridge. How much of this anticlinal fold of Fordham actually brings this formation to the surface it is impossible to say, but that it may be expected to be encountered along this line is evident.

On the east side a parallel belt of Inwood limestone is indicated and this again is succeeded by a Fordham gneiss area which occupies the rest of the eastern margin. Explorations made along the line of the gas tunnel across East river at 72d street[2] indicates comparatively narrow belts of limestone there in both the east and west channels. The limited width of limestone at these points, together with the occurrence of two strongly developed disintegration zones, seem to indicate rather extensive squeezing out and faulting of this formation along fault planes

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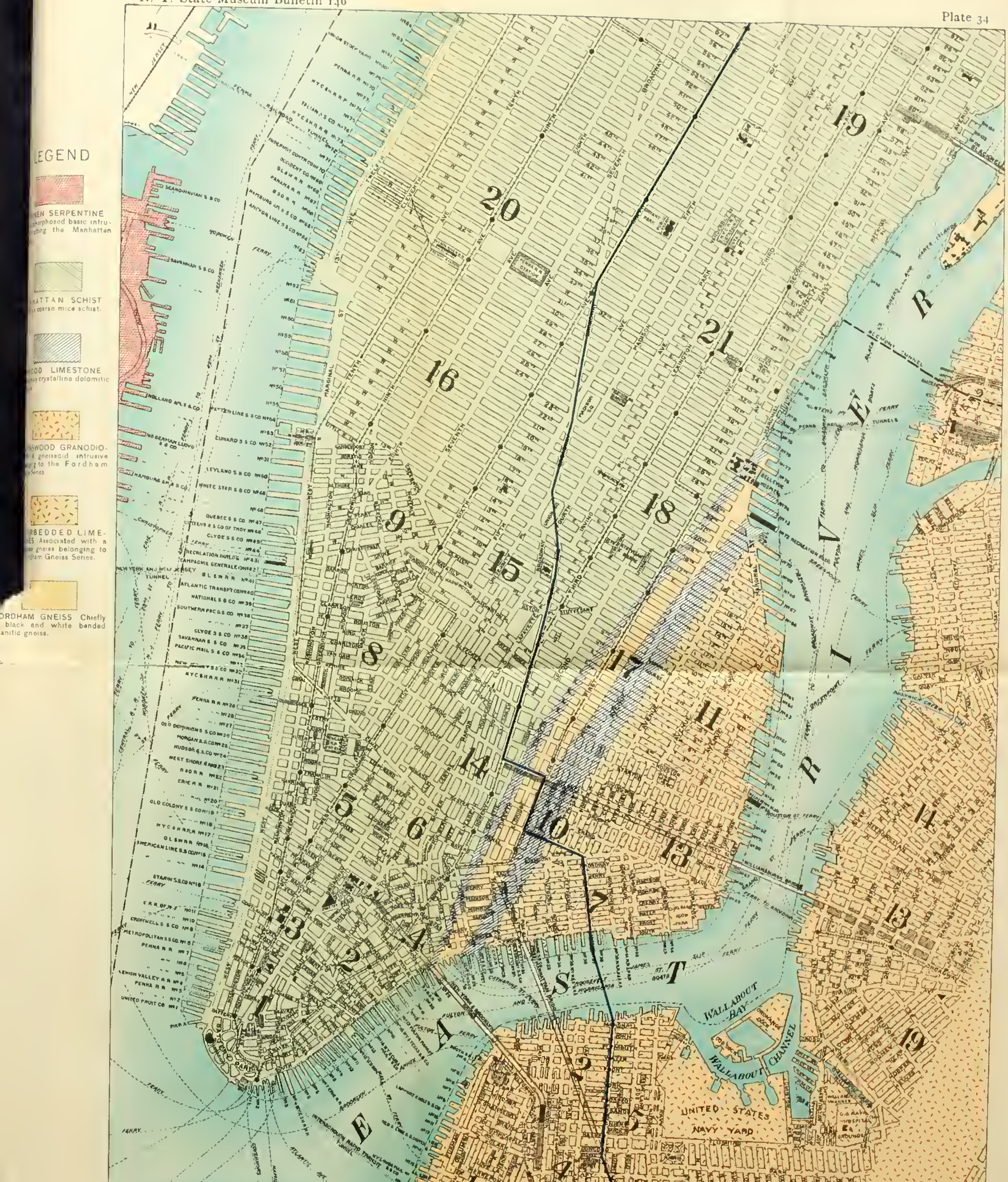
[1] In the summer of 1908 the writer was assigned the task of studying in detail the evidences of geologic structure beneath the drift in southern Manhattan. Before any drilling was attempted in the city by the Board of Water Supply, a thorough canvass was made of all previous borings in this district and the cores and records were personally inspected. More than 300 such borings were found in which some of the core could be secured for identification and classification as to formation and condition. Most borings were given no weight at all in the final summary of this evidence unless the rock core or at least fragments of it could be secured. After all of these newly assembled data were tabulated and plotted on the map, it was evident that if the identifications were correct the areal and structural map of southern Manhattan needed extensive revision. A new map therefore was made and presented to the chief engineer of the Board, October 30, 1908. This has been used since as the basis for exploration of the Lower East Side section. This original tabulation and map only slightly modified was published under the *Areal and Structural Geology of Southern Manhattan Island* [N. Y. Acad. Sci. Annals, April 1910, v. 19, no. 11, pt 2]. The extensive explorations of the board have made further revision necessary [*see* accompanying map, pl. 34]. Exploratory boring is still in progress (October 1910) and some slight modifications of boundary lines may yet be made.

[2] This is taken from Prof. J. F. Kemp's description of *The Geologic Section of the East River at Seventieth Street, New York* [N. Y. Acad. Sci. Trans. 1895. 14:273–76].



REVISED AREAL GEOLOGY OF SOUTHERN MANHATTAN ISLAND AND THE ADJACENT MARGIN OF LONG ISLAND

This revision is based upon exploratory borings to June 25th, 1910. The heavy blue line marks the course of the proposed pressure tunnel intended to carry the Catskill water to Brooklyn

parallel to the strike. Such movements are capable of cutting out the intermediate limestone entirely from between the schist and gneiss. How much of such modification exists, in the almost total lack of data bearing upon the question, it is impossible to say. The intermediate belt is indicated on the accompanying map [pl. 34], as a limestone area. At one point at least the limestone does occur in the older borings, i. e. on the southeastern margin of the Manhattan pier of the Manhattan bridge (bridge no. 3), at the foot of Pike street.

On the Brooklyn side no formations of this series except the Fordham and its associated igneous masses, such as the Ravenswood granodiorite, have been identified within the area under study. Limestone is reported (Hobbs reference to Veatch) near Newtown creek, a little beyond the eastern margin of the present map.

Structure of the East river area

Manhattan side. In all of the area south of 59th street, structural features are even more obscure than the areal geology.

There is no reasonable doubt but that weak zones will be found as frequently in the Manhattan schist portion of this area as on the line north of 59th street, but they can not be indicated as closely. No cross fault of large consequence can be identified, but there is some evidence of a minor zone that should be encountered on Fifth avenue, in the vicinity of 32d street. The Pennsylvania tunnels and the subway both cross this line and so far as known there were no serious weaknesses developed. There is nowhere any evidence of an important depression like the Manhattanville valley.

It is confidently believed that the problems on this southerly portion of Manhattan are involved chiefly with the longitudinal structures produced by folding and faulting and subsequent disintegration along such zones.

Crossing of East river

From 59th street to the East river there seems to be no reason for a preference between the two lines P and Q.[1] On the Brooklyn side likewise there is no known geological reason for preference. Such basis for choice as is now known relates to the East river channel alone. Since this is at the same time the most difficult section of the line to explore and probably the most uncertain section to estimate as to condition and consequent depth of tunnel, it would be especially useful to be able to make a decisive selection of crossings at once.

[1] For location of these lines *see* map, pl. 32.

Such evidence as has any bearing upon this question has already been used in formulating the interpretation of geologic structure given in the foregoing sections of this report. If the succession and boundaries of formations as outlined are reasonably close to the actual conditions, it would appear that line P (the southerly one just above Manhattan bridge) has some advantage over line Q (near Williamsburg bridge). The chief elements in this advantage are as follows:

1 It would appear that line P might lie wholly within the Fordham gneiss in the East river section, while line Q may cross two contacts.

2 From the evidence of borings made in the East river at 14th street[1] it appears probable that a belt of schist similar to Manhattan schist in quality (whether accompanied by limestone or not there is no direct evidence) lies in the river channel toward the east side and in all probability extends southward in the middle of the river at Williamsburg bridge. This would be cut by line Q. The uncertainties of this association are of sufficient importance to throw the balance of present choice toward line P.

3 If the theory that the East river course is due chiefly to zones of weakness following fractures or faults is true, their possible comparative condition as they cut through different formations must be taken into account. There is little doubt on this point but that, in zones of similar original disturbance, those in the Fordham gneiss have suffered less extensively from disintegration than those cutting either the limestone or schist. Therefore, obscure as it may be, the preference is again in favor of line P.

4 If, furthermore, the course of the river is due to cross faulting or any similar or related displacements or movements, an inspection of the structural map indicates that the controlling zone followed by the river as it crosses line Q must have a general strike northwest, while the corresponding zone that crosses line P strikes east. Of these two types (directions) of fault zones, so far as they may be judged to have influence in the adjacent area, there is no doubt but that the northwest type (the set that has a northwest strike) is both the more common and the more important. If this general tendency is also true here, then on this account also line P may be considered slightly more favored. In reality not much weight can

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[1] These borings were made by the Public Service Commission in explorations for subways.

be given to this point since the condition of these faults is not fully known.

5 If, as may well happen, the present East river is displaced[1] from its old channel by glacial drift, so that it is essentially an evicted stream, there may not be as pronounced a channel or as weak ground to cross at such points as at those where the old channel is still occupied. In such case both of these lines are favorable.

6 On the other hand, the crossing of line P is almost a mile nearer to the great Hudson gorges, to which doubtless this portion of the preglacial East river was tributary, and consequently its bed rock channel, if it is the real preglacial channel, may be expected to be deeper and the accompanying disintegration (so far as it may be controlled by this factor) may be expected to reach lower than at points in similar surroundings farther up stream. It is impossible to say how much weight should be given to this objection. It does not seem to be of sufficient importance to fully offset the favorable features indicated in items 1, 2, 3 and 4.

On the basis of these studies line P (the southerly one) near Manhattan bridge was chosen as the site of preliminary exploration promising the most favorable results. Later this was shifted a short distance without introducing any new conditions.

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[1] Exploratory borings indicate that such has been the history of the river.

CHAPTER XIX

SPECIAL EXPLORATION ZONES

Exploration by borings[1] and other methods have been made at all questionable or uncertain points along the line. As was expected in the beginning five places have required elaborate exploration and some exceptional conditions have been proven. The original geological investigation based upon surface study as outlined in the foregoing pages served to locate these spots accurately.

These places or zones, now either finished or sufficiently well known to permit accurate statement of geologic conditions, are as follows:

1 The Harlem river crossing at 167th street, where the aqueduct will cross from a ridge of Fordham gneiss beneath the Harlem river, where the whole thickness of Inwood limestone will be cut, to the ridge of Manhattan schist above the Speedway on Manhattan island.

2 The Manhattanville cross valley, a low pass crossing the island at about 125th street. The part explored extends from St Nicholas to Morningside Parks and crosses a zone with very low rock floor in the Manhattan schist.

3 From Morningside to Central Parks. The line crosses the strike of the formations at this point and cuts a longitudinal fault and anticlinal fold which tends to bring the Inwood limestone within surface influence.

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[1] Exploratory work has been in direct charge of Mr T. C. Atwood, division engineer, who has followed all stages of it almost from the beginning. In the later exploratory work an immense amount of detail and a very complex lot of data has accumulated requiring constantly the services of a man with some special geological training. Mr John R. Healey, formerly in the testing laboratory, was transferred to this special field. He is probably more familiar with the multitude of details resulting from boring operations along the conduit line than any one else. Except for the care and good judgment used by these men in preserving data, and the wisdom of the men who planned the line and methods of work before them, much valuable geologic data would have been lost. Notwithstanding the best efforts of the consulting geologist some really critical points escape unless some one constantly on the ground is directly interested in them as a part of the regular responsibility.

4 The Lower East Side zone. On Delancey street east of the Bowery, the line crosses the structure and at this point the whole series of crystalline formations appears. Besides complicated structure there is also exceptionally deep alternation or decay of bed rock.

5 The East river crossing — from the foot of Clinton street to Bridge street, Brooklyn.

1 Harlem river crossing

Geologically the Harlem river between 155th and 200th streets has the same relation to local formations for the whole distance. It flows on the Inwood limestone bed which stands almost exactly on edge, while the east river-bluff is formed by the underlying Fordham gneiss, and the west, by a strong escarpment of Manhattan schist which extends southward throughout the whole of Manhattan forming the backbone of the island.

At the selected crossing a short distance below High Bridge, near 167th street, the schist-limestone contact is in the river and appears to be a low weak spot [*see* detail of record]. The limestone-gneiss contact however is in the flat east of the river bank, near Sedgwick avenue and seems to be more substantial. The structural detail and relations are shown on the accompanying profile and cross section, [pl. 35].

It is observed by examination of the data secured by borings that the limestone formation at this point is exceptionally heavily impregnated with pegmatite dikes and stringers, and that interbedded schist layers are large and numerous.

The weakest spot found lies at the contact between schist and limestone where there is probably some longitudinal displacement.

A similar condition was found at the new Croton crossing 2000 feet farther north. On the whole bad decay does not extend very deep — 150–200 feet.

Several borings have been made and on them is based the only judgment possible of the actual structure and physical condition of rock. In most cases the evidence is easily interpreted for these points. The most weakened spot, as well as the most difficult to interpret in all its detail, is the limestone-schist contact. It is judged that hole no. 17 cut through this contact zone. This boring is located in the river 50 feet from the Speedway (west bank) on the proposed tunnel line which crosses a short distance south of High Bridge. It is known as hole no. 17/C38. Because of the

somewhat unusual quality of material at this place as indicated by the wash and core saved and because of the suggestion it gives

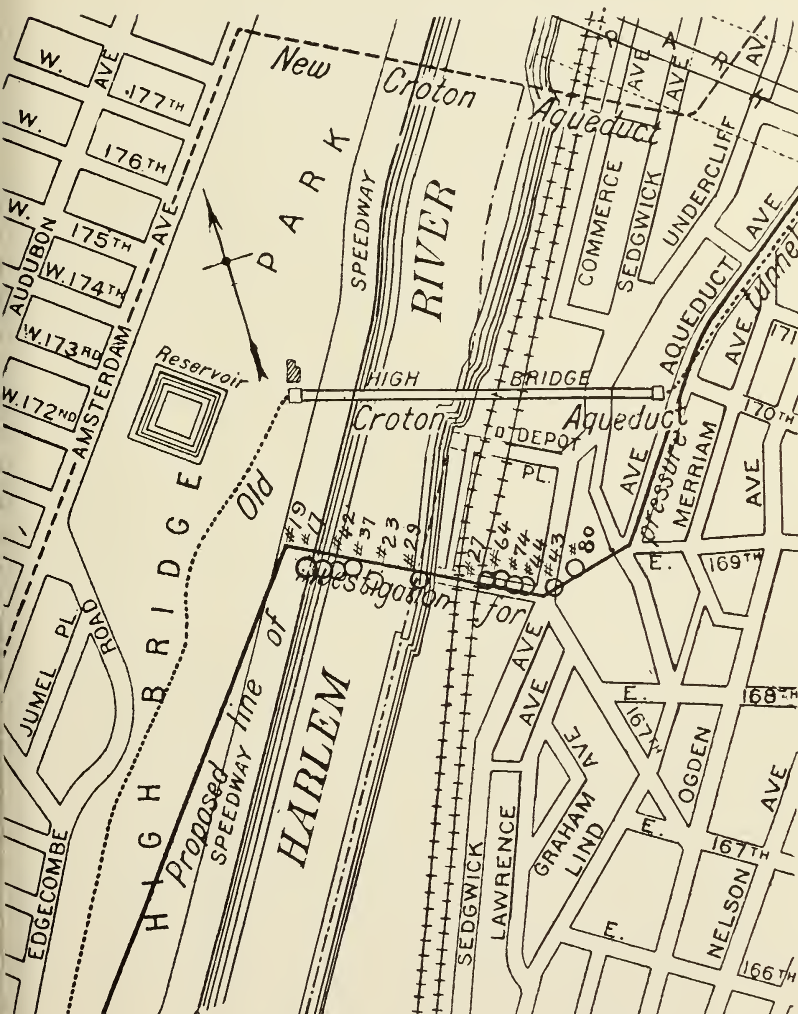

Fig. 38 Key map showing plan of exploratory borings at the Harlem river crossing, location of the New Croton aqueduct which crosses the Harlem in a pressure tunnel and the Old Croton aqueduct which crosses the river on High Bridge

about the structure and condition of rock beneath the river, the record and interpretation notes are given.

Feet	
0— 13	=Water
13— 46	=Black river mud (mostly river silt)
46— 48	=Sand with decayed wood (peaty wood)
48— 70	=Quartz and garnet sand rather clean (glacial)
46— 70	=Lumps of peaty matter coming to the surface at intervals indicating occasional small layers of peat (glacial)
70— 78	=Mixed sand (glacial)
92	=A core of Triassic contact shale (a drift boulder from the Palisade margin). At this point also a piece of Manhattan schist (boulder)
95	=4 pieces of diabase (Palisade trap) from another drift boulder
96.5	=5 pieces of Inwood limestone (boulder) followed by a piece of quartzite and several mixed pebbles indicating glacial drift origin
114—119	=A buff yellow sand with much pearly yellow mica flakes. Effervesces with acid. This shows no foreign matter. It is chiefly residuary decayed rock in place and represents silicious and micaceous limestone. It is decayed, very impure, Inwood limestone
119	=Clay with pieces of flinty quartzite, probably from a small quartzose seam in the limestone
120—126	=Light flaky yellow material. Much pearly mica with earthy matter. Effervesces in acid. Residuary from Inwood limestone
128	=White and drab lumpy residuary matter (kaolin) and earthy substances. Effervesces. A more impure Inwood. Also shows several pieces of core of a porous, rotten limestone. Inwood
129—134	=Reddish brown lumps. Effervesces a very little. Mostly clay but still no foreign matter. Residuary material from a more silicious bed. A few pieces of hard, impure limestone at 133 feet
134	=Pieces of a porous quartz chlorite rock with little lime. Is a leached quartzose rock evidently a sandstone layer in the limestone. Rock belongs to the Inwood formation

Feet

135—143=Dark micaceous matter containing chiefly biotite, a pearly mica, and quartz. Rock is a decayed schist bed=the transition between Inwood limestone and Manhattan schist

143—151=Dark brown micaceous material. Biotite and quartz — chiefly. Rock is decayed schist (transition rock). At 146 feet encountered pieces of a pegmatite veinlet. All pieces except 1 are pegmatitic — the other one is calcareous sandstone, fallen into this lot from the 134 foot level

151—160=Chunks of pegmatite (a vein rock)

151—161=The mica washings continue the same as at 143—151 feet. Rock is a transition schist with pegmatite stringers

164—169=Brownish yellow micaceous matter (loose). Mica, quartz, chlorite, lime. Effervesces

164—173=Many pieces of typical Manhattan schist. A fair amount of core for the conditions. Rock is not so badly decayed but is broken into small pieces. Rock is Manhattan schist of typical character.

Summary

1 The material is chiefly river silt down to 46 feet

2 Lighter glacial deposits 46—78 feet

3 Heavy bouldery drift 78—97 feet

4 Uncertain (insufficient data) 97—114 feet

5 Residuary micaceous decay products from Inwood limestone 114—135 feet

6 Decayed transition schist bed with some lime, but chiefly like the Manhattan schist 135—161 feet

7 More calcareous schist 161—164 feet

8 Typical Manhattan schist 164—173 feet

Interpretation

1 Foreign matters, glacial and recent deposits, continue to a depth of between 97 and 114 feet.

2 Rotten formations (residuary matter) in place begin at least as high as 114 feet. There is no foreign material below that point except grains that have fallen into the hole from above.

3 More solid rock begins at 164 feet.

4 The upper portion of the rotten rock (114–35 feet) is calcareous enough to belong to the Inwood limestone formation. The lower 9 feet (164–73 feet) is typical Manhattan schist. The intermediate ground 135–64 feet is transition variety.

5 The drill has cut the contact between Inwood and Manhattan formation.

6 If this identification of the badly decayed matter is correct, the contact at this point dips steeply eastward, i. e. it is overturned.

7 Both types of rock are shown to be extensively decayed.

8 The worst (deepest) decay zone probably lies still a little farther east, and follows the dip of the micaceous limestone near the contact.

These conditions are indicated on the accompanying cross section [*see* pl. 35].

The conditions indicated by this one hole are consistent with those known for the New Croton aqueduct tunnel 2000 feet farther north where, according to the engineers' drawings, the formations also are overturned. Fifty feet of decayed rock is shown in this hole. The contact is undoubtedly decayed considerably to a depth of more than 200 feet below water level.

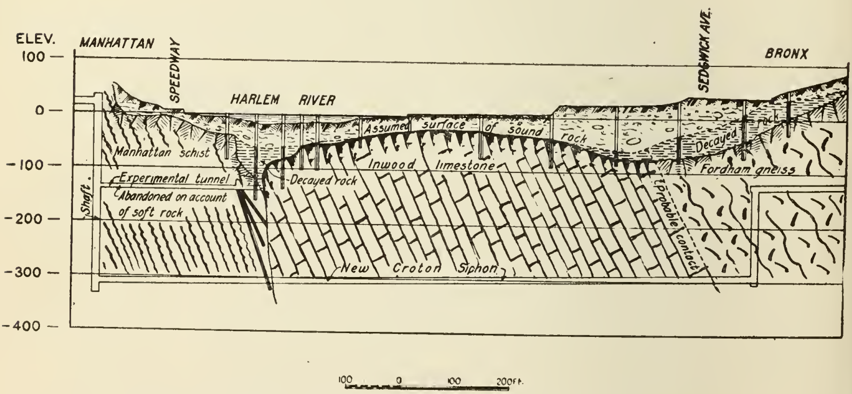

Fig. 39 Harlem river crossing — New Croton aqueduct

Another boring put down to test conditions at still greater depth nearby explored the rock to −442.7 feet. Because of the information it gives about the deeper bed rock, a summary of the record based upon examination of the material is given:

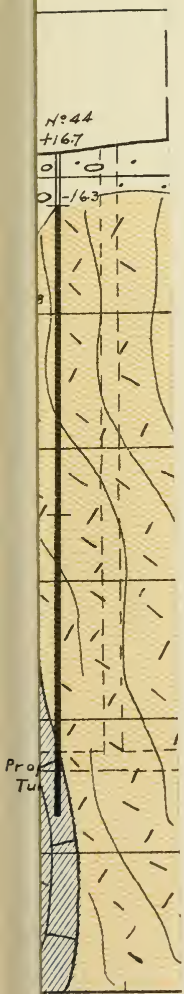

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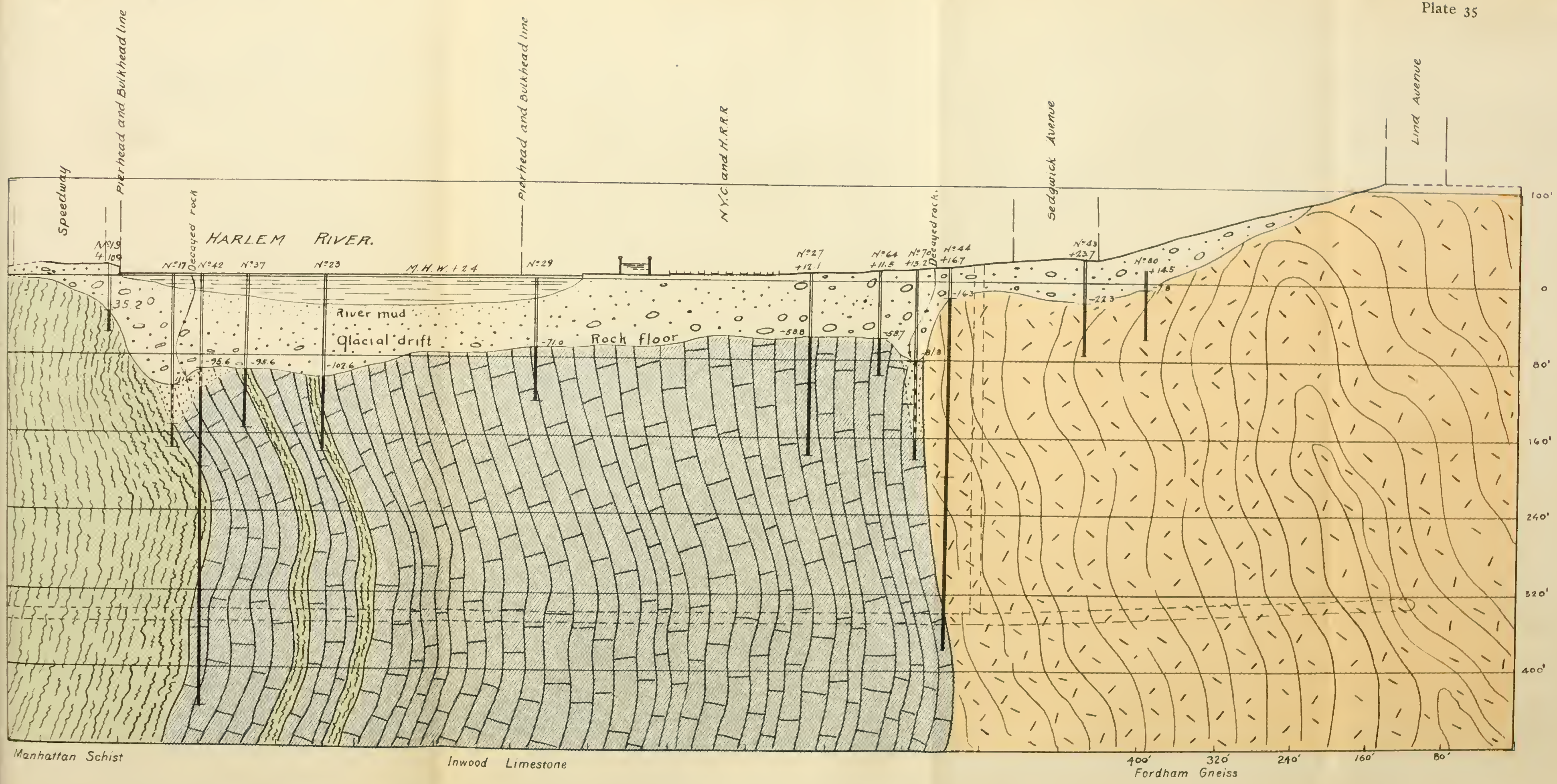
Plate 35



Geologic cross section and graphic interpretation of the exploratory borings made for the New York City Board of Water Supply at the site of the proposed pressure tunnel beneath the Harlem river, reaching Manhattan at the foot of 171st street

Hole no. 42 (75 feet from Speedway, 25 feet east of hole no. 17)

Feet		
0 to −94.1	River muds and various types of drift similar to hole no. 17
−94 to −96	Iron cemented sand — both drift sand and local angular material
−98 to −127	Micaceous clay — residuary decayed matter — with choppings of calcite, quartz, mica and chlorite representing weathered Inwood limestone
−127 to −135	Core — Inwood limestone (impure)
−135 to −149.5	Pegmatite
−149.5 to −197	Inwood limestone — typical — standing almost vertical in upper portion but changing to about 45° and farther down to 60°. Good sound rock
−197 to −241	Manhattan schist — of typical sort — and in sound condition, but becoming somewhat more broken and altered near the bottom. Dip about 60°–80° and even more. Average probably 75°–80°
−241 to −295	Manhattan schist — typical — dip variable but mostly above 70° to vertical — some pegmatite — fractures are at high angle. Rock sound
−295 to −302.5	Pegmatite
−302.5 to −442.7	Inwood limestone — typical — good quality — dip 70° to very flat — one piece not over 35° but mostly obscure

An interpretation summary is as follows:

Feet	
0 to −94	River muds and drift filling (glacial and recent)
−94 to −96	Transition to residuary matter
−96 to −127	Residuary matter and badly decayed Inwood limestone
−127 to −197	Inwood limestone
−197 to −302	Manhattan schist
−302 to −442.7	Inwood limestone

Geologic cross section. The accompanying cross section [pl. 35] embodies an interpretation of all the data secured in the Harlem river. It is now known that the limestone is overturned

slightly at both contacts. The nature of these contacts makes it seem probable that there is very little of the limestone squeezed or cut out by movement. Therefore this crossing gives a fairly accurate measure of the thickness of the Inwood. This is approximately 750 feet. No section about New York city is more accurately determined.

2 Manhattanville cross valley

In northern Manhattan the schist ridge which forms the backbone of the island and has a relief of more than 100 feet, is cut across by a prominent valley that extends from the Hudson at 130th street eastward to the Harlem Flats and East river. This valley is nowhere more than 25 or 30 feet above the sea level and is drift filled. Previous to the recent boring explorations of the Board of Water Supply its true depth to rock floor was unknown. The few borings recorded, however, indicated a depth of more than a hundred feet. One such boring at 129th street and Amsterdam avenue is reported as penetrating 109 feet from surface without touching rock. Another of similar results is located at 125th and Manhattan streets where a depth of 204 feet failed to touch rock.

Besides determining rock floor in the present case, it was important to determine rock structure and conditions. It appears from surface features that this cross valley probably follows a fault zone along which there has been weakening of the rock and consequent disintegration and decay. If this is so it would be advantageous to find the limits of it and determine what displacement effects were produced. It has been surmised by all students of local geology that such cross faults may lift the blocks on the south side of them, one of the chief indications being the fact that in spite of a strong southerly pitch in all the formations they do not rapidly disappear below sea level.

The accompanying profile and explanatory section indicates the principal results of exploration [*see* pl. 36]. Badly crushed ground has been found in the holes near the north end of Morningside Park but the rock, when found, is not very badly decayed. The rock floor is very low, almost 200 feet below sea level at the lowest. It appears that if the drift were stripped off from this valley the Hudson and Long Island sound would unite across the Harlem Flats and Manhattanville forming a channel and outlet much deeper than the present East river course.

The glacial drift of this valley is prevailingly fine modified drift some of which is probably stratified and fairly well assorted.

This is more strikingly true of the southerly extension of this low ground southward along Morningside Park. A very deep and prominent preglacial stream came down from the gap between Morningside and Central Parks.

It is not yet proven that the fault has really raised the Morningside block. At least if there is such displacement it is not of sufficient amount to bring up a different formation at any point yet examined. It would be possible for the limestone to be brought up to the surface, but except for a few pieces of interbedded limestone no evidence has been secured. The occurrence of this, however, is thought to indicate proximity to the limestone contact.

General geologic conditions established. Fourteen borings have been made for the special purpose of determining exact conditions. On the data of these holes there are several features now established beyond question that were originally given only as probabilities. The most important of these may be enumerated as follows:

1 A very deep cross valley is now proven between 123d and 126th streets, and its profile can be plotted.

2 A part of this ground is badly broken, as if belonging to a fault zone, but most of the floor thus far tested is not in bad condition, i. e. it is not very badly crushed or decayed.

3 The drift cover in this cross valley is more than 200 feet deep over a distance of more than two blocks on the proposed line (from 123d street to Manhattan street).

4 The limestone contact lies more than 300 feet east of the proposed line at this Manhattanville cross valley.

5 At 121st street the limestone-schist contact stands very steep and is probably slightly overturned. This is indicated by the data of hole no. 33.

6 The contact line approaches nearer to Morningside Park in passing southward, touching the park between 110th and 113th streets and the contact is probably not overturned in this southerly extension.

3 Morningside to Central Parks

The contact between Inwood limestone and Manhattan schist follows nearly parallel with the Morningside Park boundary on the east side, but, because of its form, actually touches the park only at the southern end between 110th and 113th streets. At the north end it lies off more than half a block to the east. The Manhattan schist forms an escarpment because of its more resistant

character and this eastward facing cliff and slope forms Morningside Park. St Nicholas Park, farther north, from 128th to 155th streets has the same structural relations. In both cases the present escarpment stands back from 200 to 500 feet from the actual contact.

As the formations all pitch southward and are pretty closely folded, the higher formations gradually appear and at 110th street another parallel ridge of Manhattan comes in above the limestone in the trough of the next syncline to the east. This forms the north end of Central Park and from this point southward Manhattan schist is continuous. But between the Morningside belt of schist and the Central Park belt at 110th street lies an anticline of Inwood limestone also pitching southward and gradually passing beneath the schist which encroaches upon it in a long wedge until a few blocks farther south it passes wholly beneath the schist, which from that point is continuous.

This anticlinal wedge and its accompanying structures and rock condition was the subject of some detailed exploration.

The records of a few drill holes together with an interpretation of all the data will serve for the present purpose.

The most important borings are summarized below:

a Hole no. 3 on 113th street, 232 feet east of Morningside Park East

Surface elevation+42.6 feet

Rock floor at depth of 81.5 feet=el. –38.9 feet.

Material:

0–19 feet=to el.+23.6 feet=soil and mixed drift

19–79 feet=to el. –36.9 feet=modified drift. Assorted sands and silts

81.5–94.58 feet=to el. –54 feet=Inwood limestone. Typical and in good condition

b Hole no. 7. On 113th street, corner of Manhattan avenue

Surface elevation+38 feet

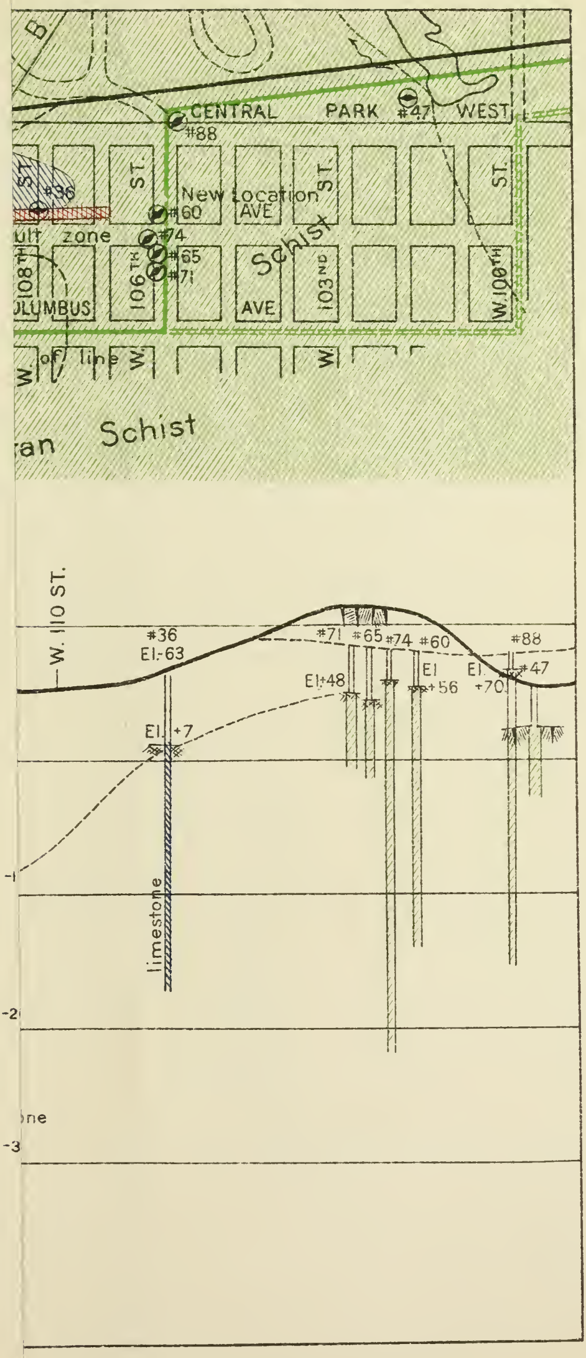
Rock floor at depth of approximately 165 feet=el. –127 feet

Material:

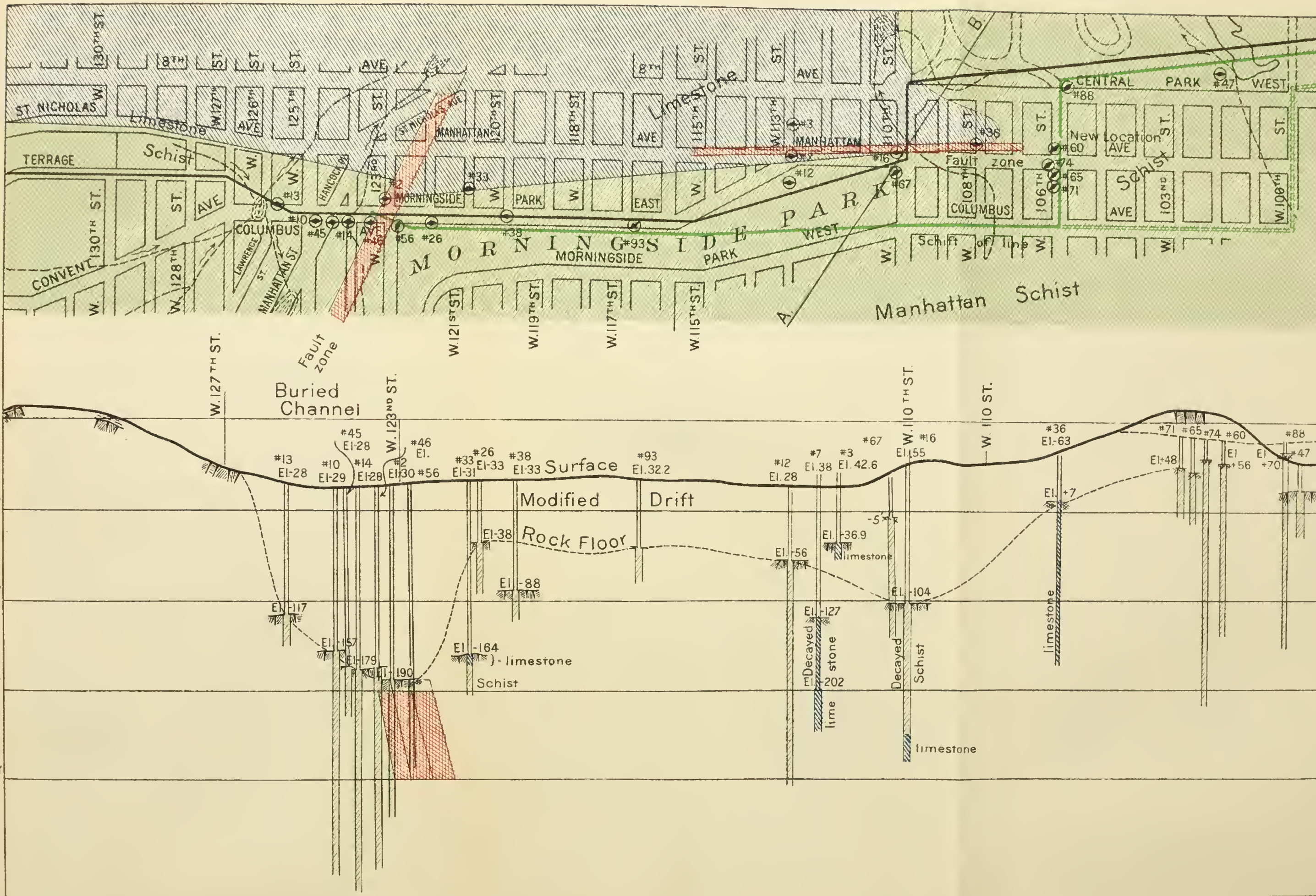
0–85 feet=to el. –47 feet=modified drift

85–165 feet=to el. –127 feet=sand with much more clay, part of which may be decayed rock

165–240 feet=to el. –202 feet=disintegrated rock ledge. Some micaceous type believed to be the transitional facies of the schist-limestone contact



ons of exploratory borings, the two



Geologic detail of the Manhattanville-Morningside section showing the alternative lines studied, the locations of exploratory borings, the two principal crush zones and longitudinal profiles

242–280.71 feet=to el. –242.71 feet=Inwood, very coarse type of limestone. Poor core showing. Much broken

c Hole no. 12. In Morningside Park at 113th street

Surface elevation+28 feet

Rock floor at depth of 84 feet=el. –50 feet

Material:

0–26 feet=to el.+2 feet=mixed drift

26–84 feet=to el.–56 feet=modified drift

84–335.15 feet=to el.–307.15 feet=Manhattan schist, typical with considerable pegmatite. But all good sound rock, not much broken and standing at about 65°–80°

d Hole no. 16. Corner of Manhattan avenue and 110th street

Surface elevation=+55 feet

Rock floor at depth of 159 feet=el.–104 feet

Material:

0–44 feet=to el.+11 feet=filled ground and mixed material

44–159 feet=to el.–104 feet=fine sands and silts interpreted as chiefly modified drift. Much of it very fine and the lower portion rather micaceous and angular throwing a little doubt on the exact line of demarcation between drift and residuary matter

159–161 feet=to el.–106 feet=core of Manhattan schist

171–186 feet=to el.–131 feet=decayed rock in place, some micaceous type, coming out as mud

186–228 feet=to el.–173 feet=micaceous reddish mud with variable amounts of angular quartz grains. Certainly residuary decayed rock

228–270 feet=to el.–215 feet=similar residuary matter less highly colored passing from reds into grays and coming out as soft material

270–305 feet=to el.–250 feet=grayish micaceous and quartzose residuary matters. With much silvery mica and chloritic grains near the bottom

305–335 feet=to el.–280 feet=Inwood limestone, *core,* ordinary type. No more recovered above this point except for 2 feet between 159 and 161 feet

e Hole no. 36 at 108th street and Manhattan avenue

Elevation of surface+63 feet

Rock floor (decayed) at depth of 55 feet=el.+8 feet

Depth to solid core=248 feet=el.–185 feet

Material:

0–55 feet=el.+8 feet=modified drift (fine silts)

55–155 feet=to–108 feet=micaceous soft material with broken sand=decayed micaceous rock

155–215 feet=to–152 feet=reddish mud of similar constituents. Is decayed rock colored by iron

215–240 feet=to–177 feet=transition to more grayish and greenish soft matter

240–245 feet=to–182 feet=greenish mica rock=a decayed chlorite, mica quartz, schist layer

248.33–254.25 feet=from el.–185.35 to–191.25 feet=chloritic Inwood limestone

A summary of these data gives:

0–55 feet=drift

55–245 feet=decayed rock ledge

248–254 feet=solid rock ledge (limestone)

f Hole no. 2 at 123d street, 100 feet east of Morningside Park East

Surface elevation+30 feet

Rock floor at depth of 220 feet=el.–190 feet

Material:

0–13 feet=to el.+17 feet=soil and mixed drift

13–220 feet=to el.–190 feet=modified drift=mostly assorted sands and silts

220–245 feet=to el.–215 feet=soft decayed schist

245–355 feet=to el.–325 feet=Manhattan schist much broken — poor core recovery — worst material at about 225–240 feet and again near bottom. Formation evidently much shattered and considerably decayed

g Hole no. 33 on 121st street, 300 feet east of Morningside Park East

Surface elevation+31 feet

Rock floor at depth of 195 feet=el.–164 feet

Material:

0–25 feet—soil and mixed drift

25–195 feet=to el.–164 feet=drift, mostly modified drift=assorted sands and fine silts

190–195 feet coarser material—pebbles

195–200 feet=to el.–169 feet=Inwood limestone, coarser limestone of usual type

200–237 feet=to el.–206 feet=Manhattan schist

Ordinary type and in good condition [for interpretation *see* later comments]

Condition of the limestone schist contact. The finding of Inwood limestone above the Manhattan schist in hole no. 33 at 121st street east of Morningside and the fairly sound condition of both types raises the general question of the condition of contact zones as compared with fault zones.

There are three important facts to consider bearing on this case: (1) The contact zones are commonly weaker than either formation alone and (2) at this particular point an abnormal relationship is shown by the overturned strata (the limestone lying above), and (3) the fault zones are always weak and extensively decayed.

Because of the abnormal position of the limestone here, lying as it does overturned, a weaker more pervious rock upon a more substantial and less pervious one, it appears to be reasonable enough to find the limestone and schist fairly well preserved, under conditions where a vertical or a normal position would have encouraged decay because permitting a more ready circulation.

But there is a further conclusion that seems allowable, i. e. the fault or crush zones are more extensively decayed than the simple contact or transition zones. And contrariwise, where an especially extensive decay is encountered, it probably is to be associated with a crush zone due to fault movement rather than with any other structure.

A further inference seems allowable from the data of these holes. It is probable that these fault zones do not follow the contacts or bedding exactly but cut across at low angles, sometimes coinciding with the contact lines and sometimes falling wholly within the limestone or the schist.

Great depth of decay at south end of Morningside Park. The finding of approximately 150 feet of decayed rock in hole no. 16 and of nearly 200 feet of similar type in hole no. 36, all so rotten that the material came up as a mud, raises a very difficult question as to the conditions that make such extensive decay possible.

Hole no. 7 (113th st.) shows extreme decay to elevation –204 feet
Hole no. 16 (110th st.) shows similar condition to elevation –250 feet
Hole no. 36 (108th st.) shows similar condition to elevation –185 feet

These three holes showing similar condition of very deep decay are located almost exactly in line. Nothing on either side of this line is in so poor condition.

Consideration of these conditions can not fail to raise certain questions of interpretation.

1 It would appear that at least one of these borings (no. 7) is near the schist-limestone contact. May they all lie then in the weakened contact zone?

2 It is true that at least one core (also from no. 7) shows a badly broken condition. May they all lie in a fault zone?

3 There is no reasonable doubt but that the geologic structure at the south end of Morningside Park is that of a pitching anticline carrying the limestone beneath the schist in its southward extension. May the excessive decay be due to this relation?

The evidence on these various possibilities is not complete enough to make a conclusion very reliable. But there are two or three factors that have a bearing and they unite pretty well in supporting one view.

These factors are: (*a*) the exact alinement of these three holes, (*b*) the crushed core of hole no. 7, (*c*) the overturned position of the formations 10 blocks farther north, (hole no. 33), together with the apparently normal position in hole no. 16.

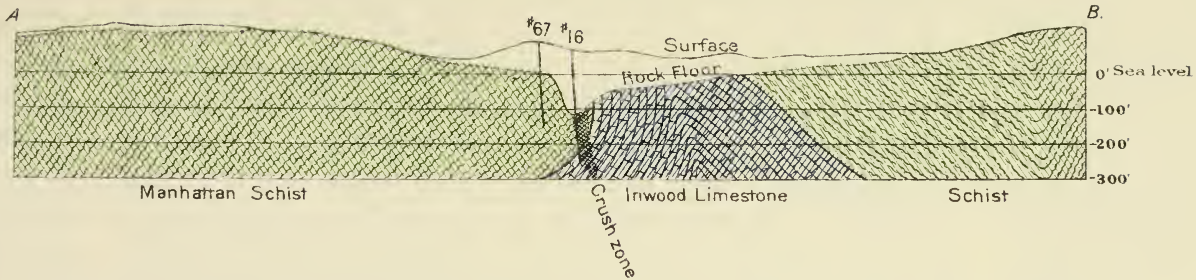
All of these points are consistent with the opinion that we have to do here with the crush zone of a fault, one that runs rather straight and one that follows not far from the contact of the schist and limestone at this point. And it is probable that the weakness follows the west margin or limb of the limestone anticline as it plunges beneath the schist. Such evidence as there is favors this view.

If that is true, then one may expect that the worst ground is not very wide, but that one probably can not go entirely around it. The best line would run south far enough to get above the limestone, and then cut across the weak zone nearly at right angles. It is certain that the ground improves southward.

Later borings are all confirmatory of the conclusion that the weakness is narrow and dies out rapidly southward as soon as the limestone passes well beneath the schist. No bad ground has yet been found on 106th street where the tunnel will probably be located.

4 The East river section

Preliminary studies of southern Manhattan and the East river led originally to the conclusion that the portion of the East river forming the great eastward bend from 32d street to Brooklyn bridge probably has a simpler geologic structure than those portions farther north or south. It was long known that the structure at Blackwells Island is very complex and involves all of the local formations in close folding and considerable faulting. But there seemed to the



Geologic cross section of the line A-B near 110th street, from Morningside Heights to Central Park, showing the anticlinal structure and location of the crush zone along which deep erosion and decay have been found

writer after studying all available data, good reason to believe that the river leaves this belt when it bends to the eastward and that it is in this part a displaced stream. In that case the East river could be flowing upon a floor of gneiss of a most substantial sort.

Explorations are now complete on a line that crosses the river from Clinton street, Manhattan, to Bridge street, Brooklyn. All borings have found good sound rock at moderate depth and all are comparatively shallow holes. Their positions and depths and rock types are tabulated below.

No. of boring	Distances in feet from Manhattan pier head line	Approximate interval in feet	Elevation of rock floor below mean sea level in feet	Type of rock	Formation
9	0	....	—48	Granodiorite	Fordham
21	225	225	—65	"	"
53	350	125	—72	"	"
32	525	175	—71	"	"
50	695	170	—76	"	"
34	860	165	—74	"	"
41	960	100	—81	"	"
39	1 070	110	—67	"	"
67	Brooklyn side near bulkhead	....	—75	Banded gneiss	"

The rock floor is thus very uniform as to contour across the East river at this point. No water course yet explored about Manhattan island has shown so simple conditions including as it does sound rock and shallow channel. The rock varies a good deal but is prevailingly a coarse grained granodiorite. In places it is very garnetiferous and at others is banded or micaceous, but all belong to the Fordham formation as a general formational unit.

Borings in the East river made by the Public Service Commission both above and below this point found an occasional deep hole with excessive decay to more than a hundred feet without securing sound core. At this crossing the deepest point in the channel to sound rock floor is 81 feet.

It is certain from these results and from others in adjacent ground that the East river does not occupy in this part of its course the original stream channel. It has been displaced (evicted) by glacial encroachment and has never been able to reoccupy the lost course. Therefore, instead of the river following a belt of lime-

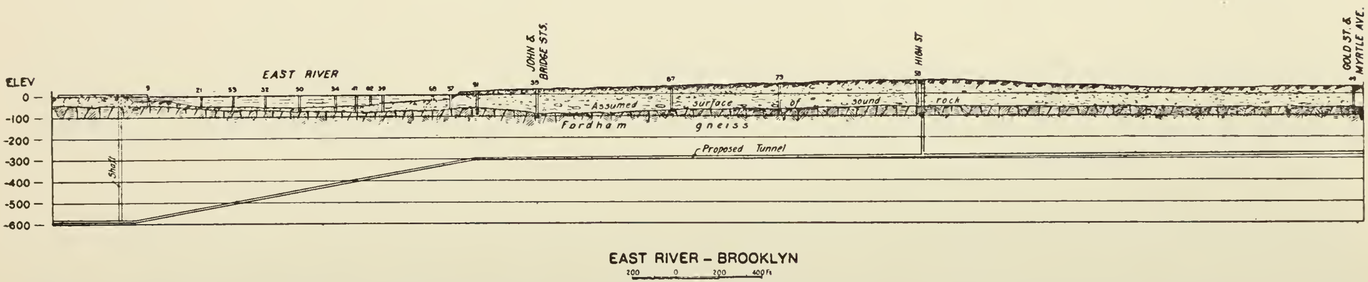


Fig. 40 Profile of surface and rock floor as indicated by borings from the foot of Clinton street, Manhattan, to Gold street and Myrtle avenue, Brooklyn. The rock floor is chiefly some variety of the Ravenswood granodiorite intrusive in the Fordham gneiss formation. It is one of the soundest rock types in New York city and the profile is more uniform than usual in any of the local formations. It is clear that the East river in this part of its course has no rock channel.

stone around this big bend as was formerly supposed, it follows no rock floor structure at all but is in this part of its course wholly superimposed. The original valley lies farther to the west cutting through the midst of the Lower East Side where the more complicated geologic structures again prevail.

Borings at intervals of 500 feet have now been made on the Brooklyn side of the East river to Gold street and Myrtle avenue. So far as developed there is no other formation than the Fordham and the associated granodiorite within the area covered. The rock floor is remarkably uniform at an elevation of from –70 to –90 feet. The accompanying section shows the relations of rock floor to present drift surface [fig. 40].

STRUCTURAL GEOLOGY OF THE LOWER EAST SIDE, DELANCEY AND CLINTON STREET SECTION

The proposed distributary conduit turns from the Bowery eastward on Delancey to Allen street, thence on Allen to Hester street, thence on Hester to Clinton street and follows south on Clinton to the East river. This so called Lower East Side section includes one of the most complicated geologic structures in New York city. The most complex portion extends from Christie street on the west side to Monroe street on the east. Between these two points all of the crystalline rock formations form a series of parallel beds that are folded together so closely that they stand practically on edge.

This general fact and the approximate location of the several beds have been proven for some time. But the more exact structure, with the depths to which the beds go before bending upward again, and the distances through each one are only approximately determined by the exploratory borings to date. The chief uncertainties arise from the fact that the beds are also faulted and the dips of the fault planes are not yet determined and the amount of displacement is unknown. The difficulty of forming a good estimate of the obscure points is greatly increased by the fact that no rock of any kind is to be seen at the surface. Judgment is based wholly on borings.

There are other important questions covering the zone, such as: (1) depth of serious decay, (2) location and width of these decay belts, (3) general physical condition of the rock at certain levels, (4) length of tunnel that will cut each formation, (5) best depth for safe construction.

The accompanying geologic cross section [pl. 38] embodies an opinion of the structural relations of the different formations. It is

offered as the writer's interpretation of borings to date, and its more direct use is as a working basis and guide in conducting explorations. The western half of the section may be accepted as more accurate in minor detail than the eastern.

To simplify the section it is drawn on a line crossing this zone more directly than the conduit as laid out, i. e. through holes 28 and 5 and the borings are projected along the strike of the formation to the section line. All the data therefore are used and the structure is not distorted, but the distances through each bed would be greater on the conduit line because it runs more diagonally across the formations.

Borings. The following tabulation of borings and interpretations upon them forms the basis of the present ideas of structure and quality of rock on the Lower East Side. The borings are given in order from west to east, and all points are neglected except those bearing upon geologic structure.

28 The Bowery and Delancey street
Surface elevation 40.5 feet
Rock floor –71 feet. Rock is Manhattan schist, and has been penetrated to –91 feet

78 Delancey street west of Christie
Surface elevation 41.4 feet
Rock floor –101.6 feet. Rock all typical *Manhattan schist* — at about 60°

224 and 301 North side of Delancey street west of Christie street
Surface elevation 42 feet
Rock floor at el. –99 feet
Manhattan schist to el.–330 feet
Inwood limestone to bottom at el. –395 feet

229 Northeast corner Delancey street and Christie street
Surface elevation 43 feet
Rock floor at el. –108 feet
Manhattan schist with very poor core recovery to el. –260 feet
Inwood limestone to bottom at el. –360 feet

84 Delancey street east of Christie
Surface elevation 41.8 feet
Rock floor –135 feet. All badly decayed schistose rock, of same type — no effervescence — red color — soft as cheese to –204 feet

227 is a reoccupation of this same hole 84
Inwood limestone was found below el. –250 feet to the bottom below el. –300 feet

63 Delancey street west of Forsyth
Surface elevation 43.2 feet
Rock floor –141 feet. Inwood limestone at 80° — very low saving of core

72 Delancey street 121 feet east of Forsyth
Surface elevation 42.6 feet
Rock floor –122 feet. Very noncommittal rock, one piece very good Fordham and the rest not decidedly any special type
Classified as Fordham on this basis. Same behavior to bottom –109 feet

81 Delancey street and Eldridge
Surface elevation 41.7 feet
Rock floor –98 feet. Rock is typical Fordham gneiss — banded and very micaceous — to bottom –123 feet

225 North side of Delancey street east of Eldridge street
Surface elevation 40 feet
Rock floor at el. –74 feet
Fordham gneiss in good condition with interbedded limestone at bottom at el. –550 feet to bottom at el. –671 feet

25 Delancey street between Eldridge and Allen streets
Surface elevation 40.6 feet
Rock floor –68.3 feet. Banded Fordham gneiss — sound rock — dip about 45°

233 South side of Broome street east of Allen street
Surface elevation 42 feet
Rock floor at el. –96 feet
Fordham gneiss with good core recovery down to el. –200 feet
This hole is also known as 302 under a subsequent contract

85 Delancey street
Surface elevation 38.7 feet
Rock floor –82.3 feet. Banded Fordham gneiss — dip about 60° or less — bottom at –171 feet

223 Grand street east of Allen street
Surface elevation 41.2 feet
Rock floor at el. –123 feet
No core recovered in the first 140 feet
Inwood limestone with dip averaging about 45° from el. –303 feet to bottom at el. –710 feet
Splendid core recovery

208 Hester street east of Allen street
Rock floor at about –145 feet
Inwood limestone with structure at about 60 feet — 70°
Enters fairly sound rock and has continued to over 600 feet with dip as low as 20°, toward the bottom

15 Delancey street near Ludlow
Surface elevation 35.7 feet
Rock floor –106 feet. Pegmatite and Inwood limestone, massive and bedding obscure

217 Southwest corner of Ludlow and Hester streets
Surface elevation 36 feet
Rock floor at el. –128 feet
Inwood limestone for more than a hundred feet succeeded by thin strips of gneiss and limestone interpreted as interbedded Fordham

222 Hester street west of Essex street
Surface elevation 36.6 feet
Rock floor at el. –130.4 feet
Fordham gneiss with interbedded limestone showing fair core recovery below el. –400 feet
Dip of rock structure about 60°

216 South side of Hester street between Essex and Suffolk streets
Surface elevation 33 feet
Rock floor at el. –167 feet
Interbedded limestone and Fordham gneiss with a dip of approximately 45° to el. –625 feet
Core recovery was variable

8 Norfolk and Grand streets
Surface elevation 35.8 feet
Rock floor –130 feet. Rock a close grained schistose limestone, Inwood, showing foliation at about 45°

231 South side of Hester street opposite Norfolk street
Surface elevation 32 feet
Rock floor at el. –103 feet
Decayed gneiss and no core recovery to el. –300 feet. This boring was continued as no. 303 under a subsequent contract and carried to el. –525 feet with only a small recovery of Fordham gneiss

218 South side of Hester street east of Norfolk street
Surface elevation 31 feet
Rock floor at el. –183 feet
No core recovered in upper 300 feet
Interbedded limestone in Fordham gneiss below el. –550 feet to bottom

77 Hester street near Suffolk [*see* 202]

202 Hester street west of Suffolk
Surface elevation 30.5 feet
Rock floor –99.5 feet. Rock all decayed to great depth
Manhattan schist to –470 feet
Fordham gneiss –470 feet to bottom at –577 feet
Believed to cross fault plane

213 Hester street 85 feet east of Suffolk street
Surface elevation 33.3 feet
Rock floor at el. –116.7 feet
The rock is Fordham gneiss of the black and white banded type, with dips varying from 30° to 80°. For a very short distance at el. –275 feet dips of 10°–15° were recorded
Core recovery very good

11 Hester and Clinton streets
Rock floor –204 feet. Badly disintegrated and no core to –279 feet. Unusual rock, identified as a mica schist of obscure structure (not typical). Some calcareous portions.

At first this was thought to belong to the Manhattan formation, but it is probably a schistose and rather unusual facies of the Fordham series. This hole was subsequently reoccupied and deepened as no. 220 under another contract with the result that an interbedded series of gneisses and limestones was shown to a total final depth reaching el –660 feet. Rock cores indicate dip of about 60°.

201 Clinton street between east Broadway and Henry street
Surface elevation –31.3 feet
Rock floor –133.7 feet
A schistose variety of Fordham gneiss with associated interbedded limestone

219 Northwest corner of Clinton and Madison streets
Surface elevation 26 feet
Rock floor at el. –214 feet
Fordham gneiss and interbedded limestone
Good core recovery below el. –400 feet

232 Southeast corner of Clinton and Madison streets
Surface elevation 25 feet
This hole was reoccupied as no. 304 and penetrated the rock floor at el. –353 feet
The boring has not progressed far enough to recover identifiable material for rock formation

211 East side of Clinton street south of Madison
Surface elevation 24
Rock floor elevation uncertain because of failure to recover core and the obscurity of the material washed up. Interbedded limestones and gneisses of Fordham series were recognized from el. –336 feet to el. –680 feet

51 and 207 Henry street between Clinton and Montgomery
Surface elevation 32.4 feet
Rock floor –214.6 feet. All badly decayed to great depth mostly believed to belong to limestone and underlain by interbedded Fordham gneiss at about –345 feet

221 Clinton street near Monroe street
Surface elevation 22 feet
Rock floor at el. –116 feet
Fordham gneiss mostly very sound, with some thin interbeds of limestone at about el. –500 feet
Dip of structure 45° to 80°

226 West side of Clinton street, north of South street
Surface elevation 10 feet
Rock floor at el. –37 feet
Fordham gneiss in very sound condition showing structure at 60° to 90°

305 Southwest corner of Clinton and South streets
Surface elevation 9 feet
Rock floor at el. –50 feet
Fordham gneiss with structure at 70°

4 Montgomery and Madison streets
Surface elevation –32.5 feet
Rock floor –65.5 feet. Fordham gneiss of granodiorite type

Two borings are of special interest and significance, and because of the rarity of such details being recorded they are given more fully below.

Each one is of great depth and indicates conditions decidedly different from the commonly accepted behavior for Manhattan Island.

Special interpretation of hole no. 202, on Hester st. near Suffolk st. This is one of the very deep borings, on the proposed distributary conduit, put down to investigate the character, condition, and structure of the rock through which the proposed tunnel would pass.

A summary of the data secured, together with an interpretation of conditions encountered follows:

1 *Boring record* (*summary*)

Elevation of surface = +30.5

a Glacial drift

0–123 feet. Soil and various types of glacial drift

b Residuary matter of local decay

130–150 red micaceous mud

c Disintegrating rock ledge too much decayed to furnish core

150–190 disintegration matter from pegmatite and associated ledge

190–214 quartz, hornblende, chlorite, mica, disintegration sand

d Decayed ledge rock capable of furnishing an occasional core

214–224 core — several pieces of coarse feldspathic, quartz mica rock

224–237 core — several pieces of core with much green mica

237–255 Cuttings and disintegration sands with much green mica

255–277 Pegmatite cuttings

277–305 Yellow clays and quartzose disintegration sands and cuttings

305–314 Core-pegmatite

314–388 Gray quartzose disintegration sands

402–447 Coarse quartz and mica disintegration sands and finer quartz-mica, hornblende-chlorite cuttings that do not look badly decayed. The rather surprising thing is their failure to core

447–463 Core — four pieces of schistose rock with white mica and garnet, nearly vertical, and three fragments of pegmatite

463–497 Cuttings only

497–512 Core — a quartz biotite, feldspar schistose rock that is rather easily disintegrated but does not show bad decay. Resembles the Fordham formation more than the Manhattan

512–531 Disintegration sand and cuttings containing abundant pearly mica

531–547 Core. Many fragments of coarse quartzose and micaceous limestone, interbedded type

c Ledge furnishing sound core

558–559 Core from quartz vein

573–588 Close textured quartz — feldspar — mica rock. Two pieces with foliation structure at about 60°

597–607 Typical banded Fordham gneiss with good structure, dip about 60°, common black and white or gray and white bands in good solid condition. Thin sections and microscopic examination of the rock indicate bottom perfectly crystalline, well interlocked, foliated rock with constituents in good sound condition

Summary of record and formation assignment

Feet	
0–123	Soil and drift
130–150	Residuary matter of local decay
150–500	Ledge rock considerably decayed — micaceous schist passing into quartzose schist or gneiss mostly badly decayed, but occasionally giving core
500–531	Quartzose rock resembling the Fordham rather than the Manhattan
531–547	A quartzose limestone probably interbedded with the Fordham
558–607	Fordham gneiss, the lowermost part of which is very sound

Discussion of meaning of this hole

There were three rather puzzling features about the data of this hole at the time it was made: (1) The fact that Fordham gneiss was penetrated at a point so far to the west; (2) the finding of a small bed of quartzose limestone in the midst of other types; (3) the finding of both schistose rock closely resembling the Manhattan and typical Fordham gneiss in the same hole with so little space between.

As to these points, the first one needs little comment. That is, it seems to mean that much more of this Lower East Side ground be-

tween Madison on the east and the Bowery on the west belongs to the Fordham than at first supposed. This very much improves the outlook for safe and easy construction.

The second one, i. e. the finding of limestone at 531 feet is probably an interbedded limestone bed and not a part of the large Inwood formation.

The third point, i. e. the finding of schists and gneisses in the same hole introduced more difficulty of interpretation. This difficulty was considerably increased by the fact that the ledge is so badly decayed and so broken up in the drilling that no typical material for identification could be secured in the upper portion. There is no doubt as to the finding of Fordham in the lower portion. Later explorations support the conclusion that the whole belongs to the Fordham series.

When this boring was first made, the schistose portion was thought to be the Manhattan formation, and the limestone could then be Inwood. Subsequent exploratory work at other points has proven that the Fordham itself shows such schistose facies rather commonly where associated with the interbedded limestones. This is now the accepted interpretation for the whole eastern half of the Lower East Side belt covered in the present discussion.

There probably is some faulting. But whether the fault plane dips east or west and how much the total movement is has not yet been developed. This, however, is a more vital question than would at first appear, for if the fault dips east the ground to the west of it is probably all Fordham of good quality and will be easily explored, whereas if the fault plane dips to the west the whole west side for several blocks is much more uncertain. It is probable that the majority of the rock lying west of it will be of better quality than found in this hole.

Interpretation of hole no. 207 (old no. 51)

On Henry street midway between Clinton and Montgomery

Drill boring no. 207 has been put down to a depth of more than 655 feet (approximately –633). The material is of unusual quality and behavior and therefore seems to require special study with a view to reaching a correct interpretation. The most essential points of the drill record are given below.

1 *Explanatory record.*

a Soil and glacial drift (surface to depth of 195 feet)

Surface to 190 feet=sands, gravels, clays of unusual variety

190–195 feet=reddish clay

b Residuary matter — mostly decayed rock (195–247 feet)

212–240 feet micaceous clay — judged to be residuary because of the abundance of mica and the scarcity of worn quartz grains and rarity of foreign particles

c Decayed rock ledge preserving original structure representing interbedded limestone (247–377 feet)

247 feet=decayed rock ledge with white blotches showing traces of structure

256–330 feet=oxidized—mostly red and brown clays and sands from disintegration of decayed rock in place

349–351 feet=gray micaceous clay

251–377 feet=quartzose and micaceous disintegration sands and calcareous clays that effervesce in acid. Much pearly mica

d Decayed rock ledge representing Fordham gneiss formation (377–489 feet) — no calcareous matter

377–489 feet=quartz and pearly mica disintegration sand varying from coarse to fine and mostly of very light buff color

e Disintegration matter from a chloritized hornblendic gneiss of too little cohesion to withstand the grinding action of a drill of so small cross section (13/16 inch). (487–532 feet)

487–532 feet=fine dark colored disintegration sand composed chiefly of quartz, chlorite and mica, the material is of same composition as the cores secured just below

f Core from more substantial rock — a hornblendic gneiss sound enough in part to withstand the drilling process and save a small amount of core (532–655 feet)

532–537 feet — 9 pieces of a green chloritic foliated rock (14 inches +) structure 70°–80° — a close textured rock much oxidized and hydrated

537–551 feet — 8 small pieces and other fragments of same rock

551–566 feet — 17 pieces and several fragments same rock. All close texture and highly chloritic

581–596 feet — 2 small pieces (two very brown, hard pieces) are probably not natural — "drillite," i. e. a peculiar product formed by the drill when it is run too dry and partly fuses fragments of rock and flakes of iron from the drill into a compact rocklike mass

611–631 feet — 14 pieces same chloritic foliated rock. Two pieces of "drillite"

One piece of fresh rock — a gray gneiss of rather worn texture

646–655.5 feet — 16 pieces of — a white and black and red blotched rock — a garnetiferous gneiss. The rock is not a common type but a similar variety is sometimes seen along the margins of the granodiorite intrusions and belongs to the Fordham gneiss series.

Rock is fairly sound and for the size of core the saving is good. (3 feet)

2 *Deflection test.* A deflection test on this hole indicates that the drill has not departed more than 5° from the vertical.

3 *Behavior of drill.* It has been possible to drive the casing down after the drill without reducing the size and without enlarging the rock hole to a final depth of 625 feet.

About half of the water fed into the machine is lost — 10 gallons per minute being fed and 5½ gallons recovered.

The hole filled after each pull up as much as 100 feet with matter that either ran in from a crevice or was furnished by disintegration of the walls or was simply the settling of matters held in suspension during operation. These settlings or corings, as the case may be, were of large amount (100 feet ±) when the drill was cutting far below the casing and small in amount (5 feet) when the casing was driven down near to the bottom. This matter then increases as the hole is deepened again below the casing.

Cutting and progress are rapid and easy.

4 *Examination of the rock.* (*a*) Hornblendic gneiss. A microscopic examination of the green hornblendic gneiss shows that the rock is not badly crushed and that the different original grains are well interlocked. But the more easily affected mineral constituents are very generally decayed and have become especially modified on their surfaces where they interlock with other grains. The matter developed is mostly chlorite — a mineral that is very soft and one that in this case fails to furnish a very firm bond between the grains. A disrupting force exceeding the strength of this soft mineral therefore, such as drilling with a small bit or forcing the drill, causes the grains one by one to roll out or break apart and furnish the suspended matter that seems to be so abundant in this hole.

b The rock below 646 feet. This is a very unusual type of rock, the petrographic character of which need not be taken up here. It appears to be simply a contact variety, such as sometimes is devel-

oped along the margins of the granodiorite masses where they cut into the banded Fordham gneiss.

The essential feature of the rock is its fresh and sound character. This rock is not decayed.

5 *Interpretation*

a Drift

The glacial drift and soil cover the bed rock at this point for a depth of at least 195 feet.

b Residuary soil

Decayed residuary matter of local derivation is detected at 212 feet.

c Bed rock

The decayed matter still preserves the bed rock structures in a sample taken at 347 feet. From this point downward there is decayed rock ledge gradually becoming more substantial

d Formations represented

After bed rock is reached the first 100 feet is so altered that identification is not certain. At 350 feet, however, the calcareous nature of some of the material is observed, and on this ground largely it is believed that an interbedded limestone layer is penetrated down to about 377 feet.

From that point (377 feet) the material is very silicious and not at all calcareous and the core when obtained is distinctly gneissoid. This lower portion below (377 feet) is therefore judged to be typical Fordham gneiss.

The bottom material is sound but a very rare variety for this formation.

e Character of contact

Normally the interbedded limestone lies conformable to the structures and beds of Fordham gneiss. The structure in such pieces as show it indicated a dip of about 70-80°. Therefore the formation must stand very steep. But, so far as can be seen in the fragments secured, there is no direct evidence of a fault contact or anything abnormal. The extremely deep alteration of the rock is the chief unusual feature. It seems to require a better chance for water circulation than is natural in the undisturbed rock of either formation. For this reason, I am of the opinion that there has been movement in this zone that weakened the rock enough to encourage water circulation.

The formation dips west in normal manner at about 75 degrees.

f Condition of the rock

That the upper 100 feet of ledge is very rotten can not be denied, but it is certain that this lower portion of the hole is not in so bad condition as the low saving of core would lead one to think. The grains are affected by chloritic alteration in such manner that they can not resist much disrupting force. The small diameter of drill used subjects the whole core to enough strain to cause the gradual pulverization of the rock. This affects both the core that has been cut loose and the hole wall that is further subjected to the thrashing of the drill rods. A larger size core would make a very much more encouraging and fair showing.

There may be an occasional small seam so badly decayed that it is encouraged to run or cave under such treatment. But there is absolutely no evidence that slumping or caving is common or even likely on any considerable scale.

The material that partly fills up the hole when the drill is pulled up is believed to be in considerable part the settlings of suspended matter which during the agitation of drilling is distributed through the rising column of water. The reduction in volume (10 gallons being fed and only 5½ gallons being recovered) due to rock porosity is favorable to such behavior of the loosened material.

SUMMARY OF LOCAL GEOLOGY.

Formations. Only three formations are represented in the rock floor of this section. These are the regular crystallines characteristic of all southeastern New York.

1 Manhattan schist

2 Inwood limestone or dolomite, and

3 Fordham gneiss, including the Ravenswood granodiorite as a special intrusive member, and an unusually strong development of the interbedded limestones and associated schistose facies.

These formations have their usual relation — the Manhattan above and youngest, the Inwood intermediate, and the Fordham underneath and older. These simple relations, however, are much complicated by dynamic disturbances of more than usual violence so that the series is thrown into folds so close that the individual beds stand almost on edge. In addition lateral thrusts of that same time or later have broken the strata and faulted them in several places. This complicates the structures still more, and, since the

amount of displacement is in no case fully known, makes the structures in some minor details impossible to accurately interpret at this stage of the work.

Fault zones. As nearly as the material recovered can be classified and accredited to the above three formations it has been done. On this identification together with the location of points of greater decay the chief fault zones are drawn. The chief ones are judged to be thrust faults but it is possible that one is a normal fault. Such a combination is comparatively rare where the zones are so close together, but it seems to best explain the relations of beds as interpreted from identification of the present borings. It is not an unknown association though in this region. It probably indicates faulting in two different periods. This is consistent with the observation also that some of the fault breccia ground is not much decayed while others are badly affected. Probably the later movements have not allowed rehealing of the crevices and they are then the lines of chief circulation and alteration.

It is clear, upon examination of the section as now known,[1] that both the eastern and western belts of limestone are too thin and narrow to accommodate the whole Inwood limestone. The Inwood normally is a formation of about 750 feet or more in thickness. It is therefore certain that a part of it has been cut out by squeezing or faulting. If by faulting then there would be expected to be in each case somewhat greater decay than usual along the fault zones. The fact therefore that such decay zones are found along one margin of the limestone bed in each case leads to the conclusion that faulting is the true cause. In some cases thrust faulting would be required to produce the result and leave the beds standing in their present relations [*see* pl. 38].

INTERBEDDED LIMESTONES OLDER THAN THE INWOOD

The finding of limestone beds within the Fordham gneiss formation so persistently in the Lower East Side borings is one of the geologically interesting and rather surprising results of recent exploration. All of the borings in the Fordham gneiss area in this particular district except those near the East river have shown some limestone.

The individual beds vary greatly in thickness, ranging from only a few inches to many feet. Because of the steepness of the dip of the beds and the obscurity of this factor in many borings it is sel-

[1] October 1910.

dom possible to compute their thickness closely. It is probable that most of them are not over 5 to 10 feet thick, although rarely a thickness of 25 or 30 feet may be represented. It is certain also that a considerable number of separate beds are penetrated. All attempts to correlate the limestone cores from different adjacent holes have so far met with little success. No doubt some of those cut at great depth in one hole correspond to others cut higher in an adjacent hole. But the differences in thickness are notable even in the best cases, and it is evident that little dependence can be put upon uniformity of thickness as a factor in correlation. The foldings and crumplings, and shearing have probably affected the limestone members of the series more than any others. Limestones in comparatively thin beds are, under such conditions, especially liable to excessive thinning and thickening through recrystallization and rock flowage. It is not at all likely that any single bed at present preserves much uniformity of thickness. In some places they are pinched out entirely while in others they may attain a thickness much greater than the original. It is possible also that some of them are repeated by folding. Whether or not this is true in the Lower East Side section no one can tell. On the whole there is no direct evidence of repetition in this way. After making allowance for all possible duplication there is still a surprisingly large number of limestone interbeds represented — probably 10 — a larger number in succession than is known anywhere else in southeastern New York [*see* pl. 38].

In petrographic character these so called limestones are all essentially very coarsely crystalline dolomitic marbles or silicated dolomites of still more complex constitution. Occasionally a very pure carbonate rock is represented that corresponds in appearance very closely indeed to the best grades of the Inwood, but there is no doubt whatever of the true interbedded relation of these limestones. Their similarity of appearance to the Inwood in certain facies is so great that from the petrographic evidence alone one could not differentiate them. Their fixed relation however is unmistakable and they belong unquestionably to an entirely different geologic formation from the Inwood — a much older one, in fact the oldest known formation in southeastern New York — equivalent to the Grenville series of the Adirondacks and Canada. The silicated facies contains many of the common products of metamorphic processes. Recrystallization has produced micaceous minerals such as phlogopite and chlorite in abundance. Original and secondary quartz is

plentiful. Serpentine, tremolite, diopside, actinolite, occasionally chondrodite, and rarely metalic ores are found. In many cases the limestone passes by transition gradually into a more and more silicious facies until the rock is simply a silicious Fordham gneiss with quartz, mica and feldspar as the essential constituents. There is seldom a sharp break between the two types. Many pieces of apparently simple gneiss will show effervescence of a carbonate constituent with acid.

The silicious beds of the gneiss series proper immediately associated with the limestone layers are also more silicious or more micaceous than the average Fordham. They are essentially micaceous quartzites and mica schists and the rock generally lacks the strong black and white banding that characterizes the common or typical Fordham gneiss of other localities. It is this facies of the gneiss which most closely resembles certain facies of the Manhattan schist, and when the rock is much decayed or badly broken or is ground to pieces by the drill the confusion is still greater. The micaceous variety may readily be mistaken for Manhattan schist and the accompanying limestone may equally be mistaken for Inwood.

The occurrence of interbedded limestones of the Fordham series is probably more common than was formerly believed. They are not very often seen on the surface areas of gneiss. Possibly this is largely due to differential weathering and erosion which together tend to obscure those portions of outcrops where such beds may occur. But the type is well known. Mr W. W. Mather in his *Geology of the First Geological District* [1843] interpreted certain limestones in the Highlands as interbedded in their relation to the gneisses there. Later workers were inclined to disregard his views on this point and there was a marked tendency to place all limestone occurrences in one formation. Some of the geological maps have been made in this way. The writer, however, raised the issue again in an article published in 1907 under the title "Structural and Stratigraphic Features of the Basal Gneisses of The Highlands," a N. Y. State Museum Bulletin 107. It is certain that there are interbedded limestones with the gneisses in The Highlands. More recently, the writer has recognized similar occurrences in the typical Fordham gneisses of The Bronx, New York city. The vicinity of Jerome Park reservoir is the best locality in all southeastern New York to see this interbedded development. The best exposures are at the following places.

1 In the margin of Jerome Park reservoir at 205th street.

2 East side of Villa avenue north of Bedford Park boulevard.

3 East of the Concourse between 198th and 199th streets.

4 South side of 196th street both east and west of the Concourse.

One of these occurrences was known to the geologists of the United States Geological Survey [New York City, Folio No. 83] but it was regarded by them as an infold of the Inwood. An examination of all four occurrences will convince one that they are not infoldings. In at least two cases the structure accompanying the beds is actually anticlinal instead of synclinal.

These occurrences in the vicinity of Jerome Park reservoir are essentially the same as those disclosed by the borings of the Lower East Side. In spite of its thick drift cover — 50 to 200 feet — there are more limestone interbeds known there than in any other area of similar size in the region. It is entirely possible that a thorough exploration in certain other belts might reveal an equally elaborate development elsewhere.

The substantiation of interbedded limestones as a prominent element in certain facies of the gneiss series and their association with typical silicious gneiss layers with transitional relation emphasizes still more the strictly sedimentary origin of at least some portions of the Fordham series. Other observations lead to the conclusion that they are the oldest members of the series and that the igneous associates, of which there are many, are all younger intrusives.

One of these later intrusives is the Ravenswood granodiorite which cuts into the eastern margin of the Lower East Side, forms the floor of the present East river channel at the point of aqueduct crossing and continues as far as explorations have been carried into Brooklyn.

Structural detail of Lower East Side

What the detailed structure of the Lower East Side is, it is impossible to say at the present stage of exploratory development. Its general features of structure are fairly clear. The Manhattan schist, which is the universal floor rock of the central and western parts of Manhattan island, extends only a short distance east of the Bowery. The Inwood limestone comes to the surface of the floor at Christie and Forsyth streets. An anticlinal ridge of gneiss comes up at Eldridge and Allen streets. Then a syncline of Inwood limestone is pinched into the next three or four blocks and from

this point eastward — from Norfolk street nearly to the East river — the Fordham gneiss with many interbeds of limestone forms the rock floor.

As much of this detail as it is now possible to classify has been included in the accompanying drawing, plate 38, in which special attention has been given to the interbedded limestone occurrences.

In view of the fact that a tunnel is finally to be constructed through this section which will cut the whole series of formations and structures at a depth probably between el. –600 and –700 feet it is clear that much greater accuracy of geologic interpretation is soon to be attainable on many of the more obscure points. Because of this also it is not advisable to attempt a detailed structural cross section at the present time. It can very well await the more complete data to be gathered during construction of the tunnel.


City of New York
BOARD OF WATER SUPPLY
CATSKILL AQUEDUCT
GEOLOGIC DETAIL OF LOWER EAST SIDE
OCTOBER 18, 1910
200 0 200 400Ft
ELEV.
Drift surface
Glacial Drift
Rock Floor
Decayed Rock
Manhattan Schist
Inwood Limestone
Fordham Gneiss Series with occasional limestone bed
Fordham Gneiss Series with many narrow Interbedded Limestones
Fordham Gneiss Series mostly granodiorite
Probable Sound
Line of Rock
The lower profile line is intended to mark the limit of rock decay as interpreted from borings. Each prominent depression probably indicates a crush zone belonging to a fault
Schist = S
Limestone L-LS.
Gneiss G
Recovery over 25% shown thus
Recovery under " " "
No Recovery " "
NOTE-
Borings are projected parallel to strike on line joining hole #28 and hole #5.
Approximate bearing of strike is N 25° E
ELIZABETH
THE BOWERY
DELANCEY ST.
BROOME
CHRYSTIE
FORSYTH
ELDRIDGE
ALLEN
ORCHARD
LUDLOW ST
ESSEX ST.
NORFOLK ST.
SUFFOLK ST.
GRAND
HESTER ST.
CANAL ST.
EAST BROADWAY
MONTGOMERY ST.
HENRY
MADISON
JEFFERSON
MONROE
CHERRY
CLINTON ST.
WATER ST.
SOUTH ST.

CHAPTER XX

THE GENERAL QUESTION OF POSTGLACIAL FAULTING

WITH ITS BEARING ON THE PERMANENCE OF ENGINEERING STRUCTURES.

Evidences of postglacial faulting and other recent movements have of late attracted a good deal of attention. The experience of San Francisco in the exceptionally disastrous earthquake and fire, traceable directly to earth movements of the nature of faulting which dislocated or injured the water conduits rendering them useless, is fresh in the minds of men everywhere who have public responsibilities of this kind. If displacements are occurring at the present time, or if any related movements are continuing, or if there is evidence of recent disturbances of this sort in this region, they have a decidedly important bearing upon the permanence of all engineering structures that cross them.

No undertaking is more vitally concerned with this question than the Catskill aqueduct. Although the principal factors to be taken into account have been considered in other connections [*see* "Faults" and "Folds," pt 1] a unified statement may encourage a more intelligent understanding of the bearing of these structures in southeastern New York on this specific question.

The region included in this discussion extends from the Catskill mountains to New York city. It will be convenient, for the purposes of this argument, to divide the whole area into three districts whose boundaries are determined by decided differences in complexity of geologic history. These lines necessarily follow closely the boundaries of greater stratigraphic unconformities. The youngest groups of strata have suffered only such changes as have accompanied movements of later geologic periods. But before they were formed the underlying groups of rocks were just as profoundly affected by earlier disturbances. In this region, at least, three such groups of large importance exist. The oldest or lowest has been affected by not only everything that has influenced the younger strata but by disturbances of a still earlier time which very much increase their complexity.

On this basis it is convenient to think of the three districts as follows:

A **Catskill district.** Including that portion of the region west and northwest of the Shawangunk mountains and marked by the

prevalence of Siluric and Devonic strata, i. e. all strata above the Hudson River slates. These strata have been affected by only one great mountain-making movement — that of the Appalachian folding, and minor disturbances of still later date.

B **Hudson river district.** This includes that portion of the region lying between the northern border of the Highlands and the Shawangunk mountains. It is marked by the prevalence of Cambric and Ordovicic strata, i. e. Hudson River slates, associated with Wappinger limestone and Poughquag quartzite as the chief bed rock. These strata have been affected not only by the Appalachian folding but also by a still earlier one — that of the Green mountains and the Taconic range. They were folded into mountain ranges and worn down in part again before the Siluric and Devonic strata of district *A* were in existence. Therefore as a structural problem this district (*B*) is approximately twice as complex as the other.

C **Highlands district.** This includes all of the region commonly known as the Highlands of the Hudson as well as the rest of the area south of the Highlands proper to New York city. Its rocks are the oldest — much the oldest. They had been folded into mountain structures and in part worn down before any of the others were accumulated. They have also suffered extensive igneous intrusion so that in places these igneous types prevail. And besides they have been metamorphosed far beyond the point of any other group. No other series of strata has been so profoundly affected. They form the lowest group. All things considered this district should be structurally three times as complicated at the first one (*A*), and adding the igneous and metamorphic complexities, it is probably more near the truth to consider this Highland district four or five times more complex.

All of the formations from the oldest to the Middle Devonic are involved. For the specific formations and their succession and relation the reader is referred to that discussion in part 1 [*see* p. 29, *et. seq.*].

Structural features

Except the most westerly part of the region, that occupied by the Upper Devonic strata, all formations are compressed into folds. Many of the smaller folds, especially those in the Catskill district, are still complete. The easy subdivision of strata possible in this district also simplifies the problem of detecting small changes of altitude. But for the most part the larger folds have been beveled off extensively by surface erosion so that only the truncated limbs

are now to be seen, and the strata therefore appear as narrow belts that dip steeply into the ground. This is more marked in the Hudson river district than in the Catskill, and is still more strikingly true of the Highlands.

There are evidently at least three different epochs of folding interrupting the processes of sedimentation and followed by periods of erosion before sedimentation was again resumed. These breaks constitute so called stratigraphic unconformities and occupy the relative positions indicated in the foregoing tabulated scheme [*see* pt 1].

In each epoch of folding the compressive forces accomplishing this work seem to have acted in a southeast-northwest direction causing successive series of folds with a northeast-southwest trend. The total amount of crustal shortening accompanying these movements is not known, but that it must be many miles is indicated by the fact that the strata of the older series of formations stand prevailingly on edge. All stages between small amount of movement to very great displacement are represented.

Accompanying the folding in each epoch there has been a tendency to rupture and displacement of the " fault " type. There are multitudes of them varying from movements of too little amount to be regarded in a broad way to those of several hundred feet. Most of the larger and more persistent ones are strike faults and follow the main ridges or valleys, sometimes governing the location of escarpments or gorges. Dip faults crossing the formations also occur and doubtless have guided the adjustments of many tributary streams, and occasionally portions of the larger water courses. The thrust fault is most common. This is especially true of the larger ones and particularly those parallel to the trend of the other structural features.

The chief effects of these movements may be summarized as follows:

1 Formations are cut out of their normal order and nonadjacent ones are brought in contact.

2 Cliffs (escarpments) and sharp gulches are more common.

3 Crush zones (belts of brecciated material) are developed.

4 The crush zones give an additional control of stream adjustments.

All of these effects are common. Many of those faults dating back to the earlier epochs are obscure and not readily located. Many of the older weaknesses of this sort have been healed by recrystalli-

zation so that they are now as sound as any other portion of the rock. A good deal depends upon the type of rock and the conditions under which the movement took place. In some of the more open ones, circulating water has seriously affected the rock and in places there is extensive decay even in the harder crystalline formations.

Age of the faulting. The chief epochs of folding and faulting are those of the mountain-making movements — one Precambric, another Postordovicic, and still another Postcarbonic. All of these date very far back in geologic history, and since the last of these, nothing akin to them in importance has been felt in the region.

In Posttriassic times however there was small faulting south of the Highlands, that affected the areas of Triassic rocks of New Jersey and Connecticut.

Whether or not there continued to be slight movement along some of the older lines it is now impossible to say. It is at least clear that all of the great movements belong to very ancient time, and that the last period of geologic time as we know it for this region, has been one of comparative stability. The chief exception is evidently connected with the continental elevations and depressions of the glacial epoch.

Recent movements. The effects of glaciation make it possible to determine whether or not there has been further movement in postglacial time. Conditions are not everywhere favorable enough to detect minute changes, but where they do obtain, the evidence is capable of very definite interpretation. The essential features of these conditions are

1 A bed rock ledge that has been left well smoothed by glacial scouring.

2 Protection from postglacial destruction so that the original unevenness as left by the glacial smoothing can not be mistaken.

If on such a ledge, as now exposed, there are steplike offsets or minute escarpments that could not have remained had they been present during the ice action, then there must have been displacement to this extent, since the original smoothing took place.

A few such evidences have been found in New York and New England, and have been noted in geologic reports. W. W. Mather in his report on the First District of New York (1843) pages 156–57, was the first. The data as now known may be found in the last bulletin of Geologic Papers of the New York State Survey [*see* N. Y. State Mus. Bul. 107 (1907) p. 5–28]. The following para-

graphs are intended as a brief summary and comment on the facts as there given:

Localities where some postglacial displacement has been detected.

1 Copake, N. Y., on the eastern border of the State near the southwest corner of Massachusetts

2 Rensselaer, N. Y.

3 South Troy, N. Y.

4 Defreestville, N. Y. (near Troy)

5 Pumpkin Hollow, N. Y. (near Copake)

6 Kilburn Crag, N. H.

7 Port Kent, N. Y. (uncertain)

8 Attleboro, Mass.

In addition to these there is reference to similar occurrences at St John, N. B. and in the province of Quebec. All of the known localities lie a considerable distance beyond, north and northeast, of the Catskill aqueduct line.

Causes of displacement. In southern New York all of the cases of postglacial faulting yet discovered lie in the area of slates belonging to the Hudson River series. Whether the belt now occupied by this formation is therefore to be considered the most unstable zone, or whether there is some tendency to slight readjustment inherent in the slates themselves causing these movements, is not clear. It would seem consistent with known recent geologic history to connect these displacements with the general elevation and subsidences accompanying and following the glacial occupation. It is perfectly clear that the whole continental border in this region suffered considerable subsidence during glacial time. Also the terraces and deposits along the Hudson prove beyond question that during the ice retreat, at the very close of the glacial occupation, the land surface stood from 80 to 150 feet lower than now. Therefore an elevation of this amount has occurred in postglacial time, and probably, judging from the condition of the terraces themselves, took place soon after the glacial ice withdrew.

The stresses and inevitable warpings accompanying these mass movements seem to be sufficient to account for all displacements known to be of this age. There is nothing in them that necessarily promises a renewal of mountain folding. But it appears that the movements have almost all been of the thrust character and in this respect they differ not at all from the commoner type of the region.

Amount of displacement. The greatest throw noted on any single Postglacial fault in eastern New York is given by Woodworth as 6 inches, and he remarks that this is imperfectly shown. Usually the displacement is distributed over a zone in which several small faults occur instead of a single larger one. This may mean that the whole disturbance is essentially superficial.

At South Troy it is stated that a total displacement of 12 inches is thus distributed through a number of small faults within a distance of 30 feet.

At Rensselaer a total of 5 inches is given.

At Defreestville a total of 13 inches is indicated in a distance of 11.67 feet.

At Copake, at two different spots, a total of more than 7 inches was measured within a space of 12 feet. Woodworth thinks that the total displacement for the locality may exceed 2 feet.

At Pumpkin Hollow a total of 17 inches is estimated.

Conclusion. If such rates prevail over larger areas beneath the drift, it is clear that rather profound changes would be indicated. But thus far there is no indication of such continuity.

Likewise if it were certain that the movements are now in progress, it would be a matter of greater concern. But there is no direct evidence to prove it.

Estimates of the length of postglacial time differ greatly. The shortest ones worthy of consideration range from about 5000 to 10,000; the longest run above 100,000 years.

Some intermediate value is probably nearer the truth — say 25,000 years.

Adjusting the postglacial faulting problem then to these time estimates the summary of it all would be as follows: Somewhere within postglacial time, i. e. approximately 25,000 years, movements of strata have developed at a few places in eastern New York that appear as small faults with total throw in each locality varying from a few inches to perhaps as much as 2 feet. Whether the movement has been gradual and continuous or concentrated largely into some small portion of this time is not known. Whether the effects are extensive or, on the contrary, very local and superficial, is likewise unknown. But in any case there are no known instances of violent and large displacements, such as would be likely to cause great damage to sound structures, in this region in postglacial time.

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New York State Education Department

New York State Museum

JOHN M. CLARKE, Director

PUBLICATIONS

Packages will be sent prepaid except when distance or weight renders the same impracticable. On 10 or more copies of any one publication 20% discount will be given. Editions printed are only large enough to meet special claims and probable sales. When the sale copies are exhausted, the price for the few reserve copies is advanced to that charged by second-hand booksellers, in order to limit their distribution to cases of special need. Such prices are inclosed in [ ]. All publications are in paper covers, unless binding is specified. Checks or money orders should be addressed and payable to New York State Education Department.

Museum annual reports 1847–date. *All in print to* 1894, 50c *a volume,* 75c *in cloth;* 1894–*date, sold in sets only;* 75c *each for octavo volumes; price of quarto volumes on application.*

These reports are made up of the reports of the Director, Geologist, Paleontologist, Botanist and Entomologist, and museum bulletins and memoirs, issued as advance sections of the reports.

Director's annual reports 1904–date.

1904. 138p. 20c.	1907. 212p. 63pl. 50c.
1905. 102p. 23pl. 30c.	1908. 234p. 39pl. map. 40c.
1906. 186p. 41pl. 35c.	1909. 230p. 41pl. 2 maps, 4 charts. *Out of print.*

These reports cover the reports of the State Geologist and of the State Paleontologist. Bound also with the museum reports of which they form a part.

Geologist's annual reports 1881–date. Rep'ts 1, 3–13, 17–date, 8vo; 2, 14–16, 4to.

In 1898 the paleontologic work of the State was made distinct from the geologic and was reported separately from 1899–1903. The two departments were reunited in 1904, and are now reported in the Director's report.

The annual reports of the original Natural History Survey, 1837–41, are out of print.

Reports 1–4, 1881–84, were published only in separate form. Of the 5th report 4 pages were reprinted in the 39th museum report, and a supplement to the 6th report was included in the 40th museum report. The 7th and subsequent reports are included in the 41st and following museum reports, except that certain lithographic plates in the 11th report (1891) and 13th (1893) are omitted from the 45th and 47th museum reports.

Separate volumes of the following only are available.

Report	*Price*	*Report*	*Price*	*Report*	*Price*
12 (1892)	$.50	17	$.75	21	$.40
14	.75	18	.75	22	.40
15, 2v.	2	19	.40	23	.45
16	1	20	.50	[*See* Director's annual reports]	

Paleontologist's annual reports 1899–date.

See first note under Geologist's annual reports.

Bound also with museum reports of which they form a part. Reports for 1899 and 1900 may be had for 20c each. Those for 1901–3 were issued as bulletins. In 1904 combined with the Director's report.

Entomologist's annual reports on the injurious and other insects of the State of New York 1882–date.

Reports 3–20 bound also with museum reports 40–46, 48–58 of which they form a part. Since 1898 these reports have been issued as bulletins. Reports 3–4, 17 are out of print, other reports with prices are: